GRIT, MINDSETS, AND PERSISTENCE OF ENGINEERING STUDENTS

BY

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DISSERTATION

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ABSTRACT

Undergraduate engineering programs in the United States suffer from high rates of attrition. To develop the knowledge base that can inform efforts to reduce attrition rates, I conducted three studies focused on helping students persist in engineering. In the first study, I investigated whether grit would help students persist in engineering. In the second study, I explored the gritty behaviors of engineering students who persisted through academic failures. In the third study, I developed an intervention to encourage students to adopt healthy learning dispositions and behaviors to help them persist in engineering.

The first study investigates whether a noncognitive factor called Grit could predict engineering retention. Specifically, I explored whether Grit predicts one- and two-year engineering retention, and whether student characteristics and academic performance affect the relationship between Grit and retention. I aggregated data from two first-year engineering cohorts who enrolled in a large public university in Fall 2014 and in Fall 2015. I used binary logistic regression to predict retention with Grit and its two subscales, Perseverance of Effort (PE) and Consistency of Interest (CI), gender, socioeconomic status, ACT math, high school grade-point-average (GPA), first math grade in college, first-semester GPA, first-year cumulative GPA, and second-year cumulative GPA. Grit and second-year cumulative GPA were significant predictors for two-year retention but not one-year retention. PE was a better predictor of retention than Grit for both one- and two-year retention, whereas CI was not a significant predictor of retention at all. Additionally, ACT math, high school GPA, first-semester GPA, and first-year cumulative GPA were significant predictors for both one- and two-year retention. Grit's utility in predicting engineering retention relies on the PE construct. I recommend more research on the CI construct to better understand how it relates to Grit and success. Though PE is a statistically significant predictor of retention, estimates of predictive power suggest that PE should not be used to predict engineering retention.

The second study explores the gritty behaviors of engineering students who persisted through academic failures. Academic failures can influence students to depart from engineering programs. In addition, researchers have identified many reasons for why students depart from engineering including perceived academic difficulty, chilly climates, and poor teaching and advising. However, the problems that departers experience are not unique to them; persisters share the same kinds of problems. To better understand the experience of persisters, I explored the experiences of persisting engineering students who had previously failed a required technical course. I used phenomenography as the qualitative research method to construct categories of description that describe the variety of ways persisting engineering students experienced academic failures. Based on 26 student interviews, I constructed four categories to describe their failure experiences: Unresponsive, Avoidant, Floundering, and Rebounding. Also, I found that students do not always experience failure the same way every time; they can experience failure differently for different instances of failure. Based on our findings, I recommend that failure be normalized in engineering education, and that course and program policies be revised to promote learning from failure.

The third study entails the development of a course to encourage students to adopt healthy learning dispositions and behaviors to help them persist in engineering. Healthy learning dispositions encompass attitudes and beliefs that promote learning. Healthy learning behaviors comprise actions such as planning, monitoring, and reflecting that produce effective learning. I used the design-based research methodology to bridge from laboratory studies to classroom implementation. Following design-based research, I used the Transtheoretical Model of Health Behavior Change to guide this translation of theories related to healthy learning dispositions and behaviors into the design of the course. I found that this course helped students adopt the growth mindset and that elements of course design helped students engage in several processes of change. This study demonstrates that theory-informed interventions, like this course, can be effective in helping students adopt healthy learning dispositions. However, more research is needed to help students adopt healthy academic behaviors.

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CHAPTER 1

INTRODUCTION

While growing up, I was interested in why some people succeed in school with little effort and why other people fail even though they work hard. As a result, my research interest developed into understanding how to help struggling students succeed, and how to convince them that they were capable of success. My introduction to engineering education research was in improving students' intrinsic motivation to learn, and my journey through graduate studies led me to my current interests in understanding how learning works and in developing students into life-long learners. For my dissertation, I had the privilege of pursuing my own research interests. My dissertation presents three studies related to helping students persist in engineering.

Chapter 2, "Should Grit Be Used to Predict Engineering Retention?" presents a quantitative study that uses binary logistic regression to predict one- and two-year engineering retention using the Grit Scale. Grit is defined as "perseverance and passion for long-term goals" and "entails working strenuously toward challenges, maintaining effort and interest over years despite failure, adversity, and plateaus in progress" (Duckworth, Peterson, Matthews, & Kelly, 2007, pp. 1087-1088). This study used a dataset provided by Dr. Beth Myers at the University of Colorado Boulder. Preliminary reports of our study were presented at three conferences (Choi & Loui, 2015; Choi, Myers, & Loui, 2016; Choi, Myers, & Loui, 2017). Chapter 2 was submitted for journal publication on February 12, 2018 and received a "revise and resubmit" decision on May 21, 2018. The authors for Chapter 2 are as follows (listed in order of appearance): Dong San Choi, Beth Ann Myers, and Michael C. Loui.

Chapter 3, “Engineering Survivors: Engineering Students Who Persist Through Academic Failures,” presents a qualitative study that explores the experience of persisting engineering students who had failed a required technical course at a large, public research university. A preliminary report of this study was presented at the 2016 American Society for Engineering Education (ASEE) Annual Conference and Exposition (Choi, 2016). Chapter 3 will be submitted for journal publication soon after the dissertation is deposited.

Chapter 4, “‘I Am Smarter Than I Thought’: Teaching Engineering Students Healthy Learning Dispositions and Behaviors,” presents a design-based research study in which I developed an intervention in the form of a course, called “Engineering the Mind,” at the University of Illinois at Urbana-Champaign. Course approval was only possible with the help of Dean Ivan Favila, who served with me as a co-instructor. The pilot version of the course was offered in Spring 2017, and a revised version of the course was offered in Fall 2017. A work-in-progress paper was presented at the 2017 ASEE Annual Conference and Exposition (Choi & Loui, 2017), a preliminary report on quantitative results was accepted for the 2018 ASEE Annual Conference and Exposition (Choi & Loui, 2018a), and a preliminary report on qualitative results was submitted for the 2018 IEEE Frontiers in Education Conference (Choi & Loui, 2018b). Chapter 4 will be submitted for journal publication soon after the dissertation is deposited.

Chapter 5, “Conclusions,” summarizes the conclusions of each study. Appendix A includes the interview protocol and research consent forms used in the study presented in Chapter 3. Appendix B includes the course syllabus, the survey, and research consent forms used in the study presented in Chapter 4.

CHAPTER 2

SHOULD GRIT BE USED TO PREDICT ENGINEERING RETENTION?

2.1 Introduction

In the United States, national reports have called on colleges and universities to improve their overall rates of degree completion (Bowen, Chingos, & McPherson, 2009), and in particular, to increase the number of science and engineering graduates (Committee on Science, Engineering, and Public Policy, 2007). Currently, however, undergraduate engineering programs in the United States suffer from high rates of attrition. The American Society for Engineering Education (ASEE) published five-year graduation rates for the 2007 freshman class, consisting of 56,393 first time, full-time students from 150 engineering colleges (Grose, 2016). On average, only 49.7% of students who began in engineering attained an engineering degree within 5 years. However, these rates varied greatly between colleges. For example, the highest five-year degree attainment rate was 97.3%, whereas the lowest rate was 4.0%.

Using the MIDFIELD database of nine institutions tracking nearly 70,000 engineering students from over 300,000 first-time students, studied over a 17-year period, Ohland et al. (2008) found that roughly half of the students who departed from engineering migrated into another major, whereas the other half departed from their original institutions altogether. According to Ohland et al. (2008), the main difference between engineering and other majors was inward migration rates, which is the percentage of students who migrate into a major after having started in another. Engineering had an inward migration rate of 7%, whereas other majors had inward migration rates of 30-65%. That is, only 7% of engineering students (in the eighth semester) had started in other majors. To increase the number of engineering graduates, engineering programs could either improve migration rates into engineering or improve the retention rates in engineering. Our study focuses on the latter: we explore factors that affect engineering retention.

Specifically, we are interested in a noncognitive attribute called Grit. Duckworth, Peterson, Matthews, and Kelly (2007) defined Grit as “perseverance and passion for long-term goals” (p. 1087). They further explained that Grit “entails working strenuously toward challenges, maintaining effort and interest over years despite failure, adversity, and plateaus in progress” (pp. 1087-1088). Previous studies have shown that Grit has a positive relationship with retention in various contexts (Duckworth et al., 2007; Duckworth & Quinn, 2009; Eskreis-Winkler, Shulman, Beal, & Duckworth, 2014). However, the relationship between Grit and engineering retention has not yet been established.

In engineering programs, students must complete a long sequence of arduous technical courses over several years. Students with high Grit may be more likely to persist in engineering programs than students with low Grit. For our study, we investigate whether Grit predicts retention for the engineering student population. The results of this study will help us determine whether improving Grit is a viable strategy in improving engineering retention. For example, measuring Grit might be useful in identifying at-risk students, and interventions aimed at improving students’ Grit might help students persist in engineering. We also explore whether student characteristics and academic performance strengthen or weaken the relationship between Grit and retention. For example, Grit may predict retention more accurately for students with low academic performance than for students with high academic performance. Overall, we hypothesize that students with higher Grit would be more likely to persist in engineering.

We have two main research questions:

1) How well does Grit predict one- and two-year engineering retention?
2) How do student characteristics and academic performance affect the relationship between Grit and retention?

2.2 Background

2.2.1 Retention in engineering

Several studies have focused on reasons for attrition from undergraduate programs in science and engineering. In a study across seven institutions focusing on students studying science, technology, engineering, and math (STEM), Seymour and Hewitt (2000) identified four major factors in students' decisions to depart from STEM majors into non-STEM majors: loss of interest in the STEM discipline, interest gained in a non-STEM major, poor teaching by STEM faculty, and feelings of being overwhelmed created by the pace and load of STEM course demands. Additional factors included choosing a STEM major for inappropriate reasons, inadequacies in advising or counseling, and insufficient high school preparation. Since persisters in STEM majors shared the same experiences, however, it is difficult to determine why students departed and why students persisted. Furthermore, this study aggregated all STEM majors together. In contrast, in our study, we focus specifically on engineering students, because differences between persisters and departers in engineering may have been obscured by their aggregation with the STEM population.

Some students leave engineering because they received low grades. In a study across eight colleges of engineering, Zhang, Min, Ohland, and Anderson (2006) found that the mean grade point average (GPA) of departers was 2.31 on a 4.0 scale, whereas the mean GPA of persisters was 2.99. However, with respect to STEM, Seymour and Hewitt (2000) found no significant difference in academic performance between persisters and departers. That is, departers had a mean GPA of 3.0 prior to leaving STEM, whereas persisters had a mean GPA of 3.15. One should note that departers in the study of Zhang et al. (2006) included students who switched into a non-engineering major and students who withdrew from the college entirely, whereas the persisters and departers in the study of Seymour and Hewitt (2000) were students who persisted in the major or switched to a non-STEM major, respectively. This difference may explain why departers had a significantly lower mean GPA than persisters in the study by Zhang et al. (2006), whose results included those who were forced to leave the university due to poor academic performance. Zhang et al. (2006) also found that most students who leave engineering because of low GPA do so in the first three semesters. Looking deeper at low GPAs in early semesters, Budny, Bjedov, and LeBold (1997) found a strong positive relationship between engineering graduation rate and first-semester GPA at one institution over a 28-year period. This study indicates that students with low GPA leave engineering early in their undergraduate career. However, we know GPA by itself provides limited information about why students leave, and we have already noted studies that explain why students depart from engineering *despite* their high GPAs. In addition, some students persist in engineering despite low GPAs.

In a quantitative study predicting retention at one university, French, Immekus, and Oakes (2005) used both cognitive and noncognitive factors to predict GPA and retention at the engineering major level and the university level between two cohorts. Cognitive factors included high school rank, Scholastic Aptitude Test (SAT) scores, and university cumulative GPA, whereas noncognitive factors included academic motivation and institutional integration. In predicting GPA, SAT math and high school rank were significant predictors, whereas noncognitive factors were not. In predicting retention, SAT math, high school rank, GPA, and motivation were all significant predictors of engineering retention, whereas GPA was the only significant predictor of retention at the university level. In a retention study at another institution, Hall et al. (2015) used SAT scores, high school GPA, and the Assessment and LEarning in Knowledge Spaces (ALEKS) placement test as cognitive variables; they used the locus of control scale and the NEO Five-Factor Inventory, a model of personality, as noncognitive variables. They found that SAT math, high school GPA, ALEKS, and Conscientiousness (one of the NEO Five Factors) were significant predictors of retention. In our study, we take a similar approach in using both cognitive and noncognitive variables to predict retention.

2.2.2 Grit and engineering retention

Duckworth et al. (2007) developed the Grit Scale to measure Grit. The Grit Scale comprises two subscales that measure the two components of Grit: Perseverance of Effort, and Consistency of Interest. Items on the Grit Scale are rated using a 5-point scale from 1 = *not at all like me* to 5 = *very much like me*. Consequently, higher scores indicate grittier individuals. For our study, we used the 8-item Grit Scale (Grit-S) by Duckworth and Quinn (2009) instead of the original 12-item Grit Scale (Grit-O) because the 8-item version had four fewer items and was demonstrated to be psychometrically stronger than the original version without the loss of predictive validity.

The original Grit studies (Duckworth et al., 2007; Duckworth & Quinn, 2009) reported that Grit was positively associated with educational attainment and fewer career changes among adults, with cumulative GPA among undergraduate psychology students at the University of Pennsylvania, with retention among cadets at the United States Military Academy, West Point, and with final round attained among contestants in the Scripps National Spelling Bee. According to Eskreis-Winkler et al. (2014), Grit predicted retention in the military, the workplace, school, and marriage: “Grittier soldiers were more likely to complete an Army Special Operations Forces (ARSOF) selection course, grittier sales employees were more likely to keep their jobs, grittier students were more likely to graduate from high school, and grittier men were more likely to stay married” (p. 1). Based on these positive relationships between Grit and retention, we were interested in exploring whether Grit predicted retention in engineering.

Only a few studies have administered the Grit Scale specifically to engineering students. The 12-item Grit Scale was administered to first-year engineering students (N = 374) at Northeastern University (Jaeger, Freeman, Whalen, & Payne, 2010) and the 8-item Grit Scale was administered to engineering students (N = 402) from first-year to near-graduation at a large, state-supported institution in the West (Chen, McGaughey, Janzen, Pedrotti, & Widmann, 2015). Jaeger et al. (2010) found that Grit and SAT scores were not statistically related, that there was no significant difference in Grit between honor and non-honor students, and that female students and athletes had higher levels of Grit and Consistency of Interest than the male and non-athlete subpopulations. Chen et al. (2015) found that Grit was positively correlated with students’ college GPA and that Grit scores were significantly lower for upperclassmen than for first-year students. However, neither study examined engineering retention.

Since previous studies have found Grit to be a significant predictor of retention in multiple contexts, we investigated Grit as a predictor of retention specific to undergraduate engineering programs. This chapter consolidates previous work on Grit by the authors (Choi & Loui, 2015; Choi, Myers, & Loui, 2016; Choi, Myers, & Loui, 2017). Previous works were work-in-progress papers that reported preliminary results for one first-year engineering cohort, whereas this chapter greatly expands the results to report our complete analysis and to include two consecutive first-year cohorts.

2.2.3 Grit and Conscientiousness

Duckworth et al. (2007) recognized that Grit overlaps with Conscientiousness, a personality trait that describes a person to be organized, industrious, and self-controlled. To distinguish Grit from Conscientiousness, they asserted that Grit emphasizes long-term stamina rather than short-term intensity, and that Grit specifies consistent goals and interests. For example, “The gritty individual not only finishes tasks at hand but pursues a given aim over years” (p. 1089). However, a meta-analysis by Credé, Tynan, and Harms (2016) concluded that the current Grit Scale is not much different from Conscientiousness. Furthermore, they asserted that the Perseverance of Effort component was much a better predictor of performance than either Consistency of Interest or overall Grit. These results were published after the conception of the present study. As a consequence, we did not consider Conscientiousness for data collection. However, we did analyze overall Grit, Consistency of Interest, and Perseverance of Effort separately.

2.3 Method

2.3.1 Participants and data collection

We administered a survey to students who were enrolled in the college of engineering at a large public university in the West. The 8-item Grit Scale was part of this survey, and the survey was given through a first-year engineering design course, which was required for some majors but not for others. The survey was not required for the course, and there was no compensation for survey completion. Between Fall 2014 and Spring 2016, 1571 students took the first-year engineering design course, and we collected 1443 survey responses for a response rate of 92%. This study was approved by the local Institutional Review Board (IRB#11-0651).

We obtained students' consent to use their information for research through an online consent process. Students could decline to participate in the study with no negative consequences on their standing in the course, the engineering program, or the university. We obtained student information such as gender, ethnicity, socioeconomic status, retention, and academic performance from the university's institutional database and collated them with students' Grit sores. We obtained the appropriate approval from the institutional review board for research with human participants.

We did not analyze survey responses with missing data because complete data sets were required to compare our logistic regression models. Among the 1443 survey responses, we removed responses that were not from first-year engineering students and responses with missing/absent data in the following order: 395 responses from students who were not in the college of engineering (i.e., mostly pre-engineering students), 106 responses missing high school grade point average (i.e., mostly international students), 38 responses from transfer students, three responses missing both ACT and SAT scores, 13 responses from students who entered during the spring semester rather than the fall semester, 40 responses without math grades during the first year of college, 20 responses missing Grit Scale items, one response without SES data, and one response from a deceased student. The remaining responses (N = 826) were from two first-year engineering cohorts: Fall 2014 and Fall 2015.

Students took the first-year engineering design course during the fall or spring semester, or both. We aggregated data from both fall and spring semester because not all first-year students took this design course during their first semester. For those who took the course twice and, thus, took the survey twice, we used Grit scores from their first fully completed Grit Scale because we wanted to use the Grit score that was obtained closest to the beginning of the academic year. Also, we had analyzed the two cohorts separately, but we decided to combine the two cohorts for better statistical power, and because they had similar demographic characteristics and backgrounds.

2.3.2 Measures

As predictor variables, we used Grit, Consistency of Interest (CI), Perseverance of Effort (PE), ACT Math (ACTM), high school grade point average (HSGPA), first math grade in college (MG1), first-semester GPA (SEM1), one-year cumulative GPA (CGPA1), and two-year cumulative GPA (CGPA2). Grades and GPA were on a 4.0 scale. Furthermore, we used the university's calculation of HSGPA, which capped a student's weighted GPA from high school at a maximum of 4.0.

With respect to ACTM, some students had only SAT scores, and some had both SAT and ACT scores. Using a concordance table (Dorans, 1999), we converted students' SAT Math scores into ACT Math scores. For the students with both SAT and ACT scores, we chose the higher score of the two. With respect to MG1, we used students' first math course grade in their first year. These math courses included Precalculus for Engineers, Calculus with Algebra, Calculus I for Engineers, Calculus II for Engineers, Calculus III for Engineers, and Differential Equations with Linear Algebra. We did not weight grades differently based on courses (e.g., we considered a 3.0 grade in Calculus I to be equivalent to a 3.0 in Differential Equations).

We used gender and socioeconomic status (SES) as demographic variables. These variables were used to explore moderating effects on Grit and retention. We did not use race or ethnicity because the sizes for some racial/ethnic groups were far too small. Gender was categorized as either male or female, and SES was categorized based on students' Free Application for Federal Student Aid (FAFSA). SES was divided into quartiles based on family income. However, students who did not submit a FAFSA were categorized into a fifth group for "highest income" because they did not request any financial aid. The lowest quartile group was below the 10% rule for an adequate sample size for logistic regression, and so we combined the two lower quartiles and two higher quartiles to create low and high SES groups. We included the highest income group (i.e., those who did not submit a FAFSA) into the high SES group.

2.3.3 Definition of retention

We defined retention as continuous enrollment at the university for consecutive fall and spring semesters and continuous enrollment in the college of engineering even if students switched majors within the college of engineering. Furthermore, using the Fall 2014 cohort as a reference, we defined one-year retention as being continuously enrolled from Fall 2014 to Fall 2015, and similarly, we defined two-year retention as being continuously enrolled from Fall 2014 to Fall 2016. We chose this fall-to-fall definition because we found that some students would finish the spring semester but not continue enrollment in engineering in the following fall semester. Students who switched majors within the college of engineering were categorized as persisters because they were still pursuing a degree in another engineering discipline.

Students also needed to be in good academic standing to be categorized as persisters. Academic standing was determined by this university's academic policy, and we adopted this policy for our categorization purposes. Specifically, students needed to maintain a cumulative GPA above 2.25 after their second semester to be categorized as persisters for one-year retention and after their fourth semester for two-year retention. Though we recognize that, in reality, students in poor academic standing are still considered to be persisting in engineering, we categorized these students as departers because many of these students received academic suspension and could not be continuously enrolled at the university. If poor-standing "departers" restored their cumulative GPA above 2.25 by their fourth semester without receiving academic suspension, we recategorized them as persisters for two-year retention.

In summary, students were categorized as persisters if they met these two criteria: good academic standing and fall-to-fall continuous enrollment in the college of engineering at the university. Students were categorized as departers if they left the university, if they switched into a major outside of the college of engineering, if they were not in good academic standing, or if they broke consecutive semester enrollment for unknown reasons or for academic reasons including academic suspension. Based on our sample, the one- and two-year retention rates were 82.4% and 74.1%, respectively. Table 2.1 summarizes the participants' demographic information with retention.

2.3.4 Data analysis

We tracked the Fall 2014 and Fall 2015 first-year cohorts from Fall 2014 to Fall 2017 to gather enough information for two-year retention for each cohort. We aggregated the data from both cohorts to increase the statistical power of our analysis and to increase the generalizability of our results. We used RStudio version 1.1.383 with R version 3.3.4 as our statistical software package. We also checked our results using IBM SPSS Statistics version 24. We used binary

Table 2.1: Participants' demographic and retention information

Demographic group	Sample size (n)	Persisted after one year (retained %)	Persisted after two years (retained %)
Asian	55	44 (80.0)	42 (76.4)
Black or African American	8	5 (62.5)	4 (50.0)
Hispanic or Latino	132	106 (80.3)	96 (72.7)
Native American or Alaskan Native	4	4 (100)	3 (75.0)
Two or more races	45	37 (82.2)	30 (66.7)
Caucasian	569	475 (83.5)	431 (75.7)
International	12	10 (83.3)	6 (50.0)
Male	553	451 (81.6)	407 (73.6)
Female	273	230 (84.2)	205 (75.1)
Low SES	195	157 (80.5)	139 (71.3)
High SES	631	524 (83.0)	473 (75.0)
Total	826	681 (82.4)	612 (74.1)

Note: There was one student with an unknown ethnicity who departed within the first year.

logistic regression to produce regression models predicting engineering retention. The desired outcome was represented by a value of 1 (retained), and the undesired outcome was represented by a value of 0 (unretained). We normalized all our continuous, independent variables so that we could interpret the odds ratio with respect to units of standard deviation. For example, we could compare students with average Grit scores with students whose Grit scores were higher than average by one standard deviation.

As a rule of thumb for logistic regression, the recommended sample size is 100 or 50 with a minimum ratio of one to ten for an observation-to-predictor ratio (e.g., observe at least 10% attrition rate) (Peng, Lee, & Ingersoll, 2002). In addition to the rule for sample size, the general rule of thumb for the number of predictor variables in a regression model is one predictor variable to ten sample counts of an event, limited to the lowest sample count (Vittinghoff & McCulloch, 2007). For example, we did not use ethnicity/race as a variable because our sample size was too small for specific populations, even with the two cohorts combined.

2.4 Results

2.4.1 Descriptive statistics

Before we delve into our logistic regression results, we report some descriptive statistics. We chose a standard significance level of $\alpha = .05$ for all statistical inferences. The predictor variables were found to deviate from the normal distribution according to the Shapiro-Wilk test (see Table 2.2). The null hypothesis in the Shapiro-Wilk test assumes that the population is normally distributed, and the low *p*-values indicate that the null hypothesis (of normality) was rejected.

Due to non-normality, we used a non-parametric, Mann-Whitney-U test to check for statistically significant differences with respect to gender and SES (see Tables 2.3 and 2.4). For gender differences, we found that Grit, CI, and HSGPA were higher for females than males, whereas ACTM was lower for females than males. For SES differences, we found that CI was higher for low SES students than high SES students, whereas ACTM, MG1, SEM1, CGPA1, and CGPA2 were lower for low SES students than high SES students. No other differences were statistically significant.

We also used the non-parametric Spearman's rank correlation between each predictor variable to calculate correlations (see Table 2.5). There were only three nonsignificant correlations between PE-ACTM, CI-HSGPA, and CI-CGPA2. All other predictor variables were significantly correlated to each other. The mean and standard deviation for each variable can also be seen in Table 2.5. From our sample, we observed Cronbach alpha values of .75, .77, and .69

Table 2.2: Shapiro-Wilk normality test for predictor variables

	Grit	**CI**	**PE**	**ACTM**	**HSGPA**	**MG1**	**SEM1**	**CGPA1**	**CGPA2**
W	.990	.974	.960	.977	.642	.938	.932	.958	.960
p	< .001	< .001	< .001	< .001	< .001	< .001	<.001	< .001	< .001

Table 2.3: Mann-Whitney-U test for gender

	Female (n = 273)		Male (n = 553)		Statistics	
	M	*SD*	*M*	*SD*	*W*	*p*
Grit	**3.63**	**0.51**	**3.54**	**0.53**	83227	**.016**
CI	**3.28**	**0.71**	**3.17**	**0.71**	83015	**.019**
PE	3.98	0.53	3.91	0.61	80845	.094
ACTM	**29.6**	**2.96**	**30.7**	**2.95**	58696	**< .001**
HSGPA	**3.92**	**0.14**	**3.89**	**0.19**	82160	**.019**
MG1	2.73	0.88	2.70	0.89	76352	.786
SEM1	3.12	0.68	3.14	0.64	76063	.858
CGPA1	3.10	0.59	3.08	0.61	76377	.782
CGPA2	3.05	0.56	3.04	0.60	75180	.925

Table 2.4: Mann-Whitney-U test for SES

	Low SES (n = 195)		High SES (n = 631)		Statistics	
	M	*SD*	*M*	*SD*	*W*	*p*
Grit	3.63	0.54	3.55	0.52	56760	.101
CI	**3.33**	**0.72**	**3.17**	**0.71**	53696	**.007**
PE	3.93	0.59	3.93	0.58	61415	.970
ACTM	**29.3**	**3.14**	**30.7**	**2.88**	77705	**< .001**
HSGPA	3.89	0.19	3.90	0.17	64497	.247
MG1	**2.53**	**0.87**	**2.76**	**0.88**	70739	**.001**
SEM1	**3.03**	**0.63**	**3.16**	**0.65**	69850	**.004**
CGPA1	**2.97**	**0.59**	**3.12**	**0.60**	71162	**< .001**
CGPA2	**2.91**	**0.61**	**3.08**	**0.58**	71941	**< .001**

Table 2.5: Descriptive statistics and Spearman's rank correlation matrix for predictor variables

Variable	1	2	3	4	5	6	7	8	*M*	*SD*
1. Grit	(.75)								3.57	0.53
2. Consistency of Interest	**.85***	(.77)							3.21	0.71
3. Perseverance of Effort	**.77***	**.36***	(.69)						3.93	0.59
4. ACT Math	**–.10***	**–.14***	–.03	—					30.3	3.00
5. High School GPA	**.12***	.05	**.16***	**.19***	—				3.90	0.17
6. First Math Grade	**.14***	**.11***	**.15***	**.32***	**.31***	—			2.71	0.88
7. First-Semester GPA	**.16***	**.09***	**.20***	**.33***	**.35***	**.81***	—		3.13	0.65
8. First-Year Cumulative GPA	**.16***	**.09***	**.19***	**.31***	**.41***	**.77***	**.91***	—	3.09	0.60
9. Second-Year Cumulative GPA	**.13***	.06	**.17***	**.30***	**.41***	**.70***	**.83***	**.93***	3.04	0.59

Note: The Cronbach alpha values for Grit and its subscales, Consistency of Interest and Perseverance of Effort, from our population are listed in parentheses. Also, * $p < .05$

for Grit, CI, and PE, respectively. These Cronbach alpha values were similar to the reported values in original Grit studies (Duckworth et al., 2007; Duckworth & Quinn, 2009) and indicate good internal reliability.

2.4.2 Binary logistic regression

We ran a univariate binary logistic regression using each variable as the sole predictor for one- and two-year retention, respectively. We coded 1 for retained and 0 for unretained. For gender, we coded male students 1 and female students 0, whereas for SES, we coded low SES students 1 and high SES students 0. To interpret the regression model, the statistical output includes coefficients (β) in units of logits that can be used to calculate odds ratios (ORs). We use the OR to interpret the odds of being retained based on the value of the predictor variable in units of standard deviation. For statistical inference, β is divided by its standard error to determine the Wald *Z*. We remind the readers that the values of the continuous variables were normalized.

We found that the OR for PE, ACTM, HSGPA, MG1, SEM1, and CGPA1 were all greater than one and statistically significant for both one- and two-year retention, whereas Grit and CGPA2 were positive and statistically significant for only two-year retention (see Table 2.6). This result suggests that any increase in any of these variables would increase the odds of being retained. For example, one standard deviation increase in a student's PE score would increase their odds of being retained by 24% and 29% when compared with a student with an average PE score for one- and two-year retention, respectively. CGPA1 had the largest effect with ORs of 4.40 and 3.75 for both one- and two-year retention, respectively.

Table 2.6: Univariate, binary logistic regression output for one- and two-year engineering retention (N = 826)

	One-year engineering retention						Two-year engineering retention				
Variables	β	OR	$SE\ \beta$	Wald Z	p		β	OR	$SE\ \beta$	Wald Z	p
Grit	0.16	1.17	0.09	1.76	.078		**0.17**	**1.18**	0.08	2.12	**.034**
CI	0.06	1.06	0.09	0.61	.543		0.04	1.04	0.08	0.46	.646
PE	**0.22**	**1.24**	0.09	2.41	**.016**		**0.25**	**1.29**	0.08	3.21	**.001**
ACTM	**0.27**	**1.31**	0.09	2.96	**.003**		**0.24**	**1.28**	0.08	3.06	**.002**
HSGPA	**0.40**	**1.49**	0.08	5.06	**< .001**		**0.40**	**1.50**	0.07	5.43	**< .001**
MG1	**1.08**	**2.95**	0.11	9.64	**< .001**		**0.93**	**2.54**	0.10	9.61	**< .001**
SEM1	**1.22**	**3.38**	0.11	11.02	**< .001**		**1.12**	**3.08**	0.10	11.26	**< .001**
CGPA1	**1.48**	**4.40**	0.13	11.53	**< .001**		**1.32**	**3.75**	0.11	12.05	**< .001**
CGPA2	—	—	—	—	—		**1.22**	**3.39**	0.11	11.37	**< .001**
Gender (male =1, female = 0)	–0.19	0.83	0.20	–0.96	.339		–0.08	0.92	0.17	–0.46	.645
SES (low = 1, high = 0)	–0.17	0.84	0.21	–0.81	.417		–0.19	0.83	0.18	–1.02	.306

2.4.3 Predictive power and classification tables

We estimated the predictive power of our binary logistic regression models using Nagelkerke's R^2. In logistic regression, Nagelkerke's R^2 attempts to imitate the R^2 statistic in linear regression as an interpretation for the amount of variance explained by the predictor variables (Nagelkerke, 1991). However, Nagelkerke's R^2 values on their own do not have an equivalent interpretation as the R^2 statistic in linear regression and should only be used to compare models using the same population. Table 2.7 lists the values of Nagelkerke's R^2 for each univariate, binary logistic regression model.

To understand the practical difference between Nagelkerke's R^2 values, we use classification tables. A classification table compares the predicted number of success outcomes (i.e., persisting students) with the actual number of success outcomes and similarly compares the predicted number of failure outcomes (i.e., departing students) with the actual number of failure outcomes. When constructing a classification table, the model determines the probability of a student persisting and compares the probability to a cutoff rate. The default cutoff rate is .5, but it can be changed to account for costs associated with false negative and false positive rates. For our analysis, we set the cutoff rates based on the observed one- and two-year retention rates: 82.4% and 74.1%, respectively. Furthermore, we judged the classification tables based on the true positive rate (TPR) and false positive rate (FPR) (because we want to know how well the models can identify potential departers). The TPR of departers is the number of correctly predicted departers (true positives) divided by the total number of actual departers (true positives plus false negatives), whereas the FPR of departers is the number of incorrectly predicted departers (false positives) divided by the total number of actual persisters (false positives plus true negatives).

Table 2.7: Odd ratio (OR) and Nagelkerke's R^2 for each univariate, binary logistic regression model

	One-year engineering retention			Two-year engineering retention	
Variables	OR	Nagelkerke's R^2		OR	Nagelkerke's R^2
Grit	1.17	.01		2.88	.01
CI	1.06	.00		1.04	.00
PE	1.24	.01		1.29	.02
ACTM	1.31	.02		1.28	.02
HSGPA	1.49	.05		1.50	.05
MG1	2.95	.23		2.54	.20
SEM1	3.38	.30		3.08	.27
CGPA1	4.40	.36		3.75	.33
CGPA2	—	—		3.39	.29
Gender	0.83	.00		0.92	.00
SES	0.84	.00		0.83	.00

Table 2.8 shows the classification tables with TPR and FPR using PE and CGPA1 models for one- and two-year retention. We see that the univariate PE models have a TPR of 51.7% and 51.9% for one- and two-year retention, respectively, and a FPR of 41.6% and 40.3%, respectively. In comparison, the univariate CGPA1 models have higher TPR rates of 68.3% and 68.2%, respectively, and lower FPR rates of 24.7% and 25.8%, respectively. There is roughly a 16% increase in TPR and a concurrent 15% decrease in FPR when using CGPA1 models over PE models to predict departers.

2.4.4 Interaction effects

To answer our second research question regarding how student characteristics and academic

Table 2.8: Classification tables to compare the predictive power of PE and CGPA1 models in identifying departers using true positive rates (TPR) and false positive rates (FPR)

(a) Using univariate PE models

	One-year retention				Two-year retention		
	Actual departers	Actual persisters			Actual departers	Actual persisters	
Predicted departers	75 True Positives	283 False Positives	51.7% TPR		111 True Positives	247 False Positives	51.9% TPR
Predicted persisters	70 False Negatives	398 True Negatives	41.6% FPR		103 False Negatives	365 True Negatives	40.3% FPR

(b) Using univariate CGPA1 models

	One-year retention				Two-year retention		
	Actual departers	Actual persisters			Actual departers	Actual persisters	
Predicted departers	99 True Positives	168 False Positives	68.3% TPR		146 True Positives	158 False Positives	68.2% TPR
Predicted persisters	46 False Negatives	513 True Negatives	24.7% FPR		68 False Negatives	454 True Negatives	25.8% FPR

performance affect the relationship between Grit and retention, we updated Grit-related, univariate regression models (i.e., models with either Grit, CI, or PE as the predictor variable) with a single moderating variable such as ACTM or gender. We will refer to these updated models as interaction models. These interaction models had three terms in the regression model: a Grit-related variable (i.e., Grit, CI, or PE), a moderator, and their interaction term (i.e., a product term with the Grit-related variable and the moderator). For example, in Eq. (2.1), we included *Grit* (Grit-related variable), *ACTM* (moderator), and *Grit:ACTM* (the interaction term). We will italicize equation variables names in the text.

$$Retention \sim \text{constant} + \beta_1(Grit) + \beta_2(ACTM) + \beta_3(Grit)(ACTM) \quad (2.1)$$

We used the likelihood ratio test to compare the retention prediction of the interaction model with three terms ($df = 3$) with that of a base univariate model ($df = 1$). The likelihood ratio test is an inferential statistical test that can compare the effectiveness of a regression model against that of a base model (Peng, Lee, & Ingersoll 2002). In choosing a base model, we chose univariate models with lower p-values to compare against interaction models so that the likelihood ratio test could correctly determine whether the model was improved. For example, for one-year retention, we used the univariate ACTM model ($p = .003$) as the base model over the univariate Grit model ($p = .078$) because the univariate ACTM model had a lower p-value. Otherwise, we could mistakenly judge that the interaction model was an improvement over the univariate model. Table 2.9 lists the results of likelihood ratio tests.

Based on the results in Table 2.9, we see that the Grit-ACTM, Grit-HSGPA, PE-ACTM, and PE-HSGPA interaction models were statistically better models of retention than their respective univariate models for both one- and two-year retention. Additionally, we see that the Grit-SES interaction model was a better model than the univariate Grit model for two-year retention. Table 2.10 presents the logistic regression results for these interaction models. No other interaction models were better predictive models than their univariate models.

We begin with interpreting the results for the Grit-SES interaction model from Table 2.10(e) because it is the only model that uses a categorical variable, which makes it is easier to interpret. We use Eq. (2.2) to express the Grit-SES interaction model.

$$Retention \sim 1.13 + 0.29(Grit) - 0.20(SES) - 0.43(Grit)(SES) \quad (2.2)$$

Table 2.9: Results of the likelihood ratio test ($\Delta df = 2$) comparing interaction models against univariate models for one- and two-year engineering retention

	One-year engineering retention							Two-year engineering retention					
	Grit		CI		PE			Grit		CI		PE	
	χ^2	p	χ^2	p	χ^2	p		χ^2	p	χ^2	p	χ^2	p
ACTM	**6.16**	**.046**	1.96	.376	**8.11**	**.017**		**8.32**	**.016**	1.98	.372	**12.53**	**.002**
HSGPA	**8.22**	**.016**	3.03	.219	**9.28**	**.010**		**6.38**	**.041**	1.24	.537	**11.03**	**.004**
MG1	0.41	.816	0.06	.970	1.55	.461		0.86	.651	0.12	.942	4.23	.121
SEM1	0.43	.807	0.23	.891	0.44	.804		0.34	.843	0.22	.897	1.26	.532
CGPA1	0.91	.634	0.68	.713	0.55	.757		0.34	.846	0.32	.850	1.37	.503
CGPA2	—	—	—	—	—	—		0.70	.706	0.04	.981	1.83	.401
Gender	1.95	.377	1.45	.484	0.89	.640		0.01	.950	0.20	.906	0.26	.879
SES	2.33	.312	0.87	.647	2.53	.282		**6.99**	**.030**	3.68	.159	5.07	.079

Table 2.10: Binary logistic regression results of the interaction models that were improvements over their univariate models for one- and two-year engineering retention

(a) Grit-ACTM interaction models

	One-year engineering retention						Two-year engineering retention				
	β	OR	*SE* β	Wald *Z*	*p*		β	OR	*SE* β	Wald *Z*	*p*
Constant	1.60	4.79	0.10	16.61	< .001		1.09	2.98	0.08	13.23	< .001
Grit	**0.21**	**1.24**	0.09	2.29	**.022**		**0.21**	**1.27**	0.08	2.62	**.009**
ACTM	**0.30**	**1.36**	0.09	3.25	**.001**		**0.28**	**1.32**	0.08	3.38	**< .001**
Grit:ACTM	0.12	1.12	0.09	1.31	.191		0.12	1.12	0.08	1.46	.143

(b) PE-ACTM interaction models

	One-year engineering retention						Two-year engineering retention				
	β	OR	*SE* β	Wald *Z*	*p*		β	OR	*SE* β	Wald *Z*	*p*
Constant	1.60	4.96	0.10	16.68	< .001		1.09	2.98	0.08	13.26	< .001
PE	**0.25**	**1.29**	0.09	2.75	**.006**		**0.29**	**1.33**	0.08	3.53	**< .001**
ACTM	**0.30**	**1.35**	0.09	3.18	**.002**		**0.27**	**1.31**	0.08	3.31	**< .001**
PE:ACTM	0.13	1.14	0.09	1.40	.163		0.13	1.13	0.08	1.55	.120

Table 2.10 (cont'd): Binary logistic regression output of the interaction models that were improvements over their univariate models for one- and two-year engineering retention

(c) Grit-HSGPA interaction models

	One-year engineering retention						Two-year engineering retention				
	β	OR	*SE β*	Wald *Z*	*p*		*β*	OR	*SE β*	Wald *Z*	*p*
Constant	1.60	4.94	0.10	16.61	< .001		1.08	2.94	0.08	13.10	< .001
Grit	0.18	1.19	0.09	1.86	.063		0.16	1.17	0.08	1.92	.055
HSGPA	**0.42**	**1.53**	0.08	5.17	**< .001**		**0.42**	**1.52**	0.08	5.45	**< .001**
Grit:HSGPA	**0.21**	**1.24**	0.09	2.45	**.014**		0.15	1.16	0.08	1.89	.059

(d) PE-HSGPA interaction models

	One-year engineering retention						Two-year engineering retention				
	β	OR	*SE β*	Wald *Z*	*p*		*β*	OR	*SE β*	Wald *Z*	*p*
Constant	1.59	4.93	0.10	16.52	< .001		1.08	2.94	0.08	13.01	< .001
PE	**0.23**	**1.26**	0.10	2.38	**.017**		**0.24**	**1.28**	0.08	2.92	**.004**
HSGPA	**0.43**	**1.53**	0.08	5.13	**< .001**		**0.42**	**1.52**	0.08	5.34	**< .001**
PE:HSGPA	**0.19**	**1.21**	0.08	2.43	**.015**		**0.16**	**1.17**	0.07	2.21	**.027**

Table 2.10 (cont'd): Binary logistic regression output of the interaction models that were improvements over their univariate models for one- and two-year engineering retention

(e) Grit-SES interaction model

	One-year engineering retention						Two-year engineering retention				
	β	OR	*SE β*	Wald *Z*	*p*		*β*	OR	*SE β*	Wald *Z*	*p*
Constant	—	—	—	—	—		1.13	3.08	0.09	11.99	< .001
Grit	—	—	—	—	—		0.29	**1.33**	0.09	3.08	**.002**
SES (low = 1, high = 0)	—	—	—	—	—		–0.20	0.82	0.19	–1.05	.292
Grit:SES	—	—	—	—	—		–0.43	**0.65**	0.18	–2.37	**.018**

To interpret this model, we compare the right-hand side (RHS) of the equation based on values of the predictor variables. For example, a low SES student sets the variable *SES* to 1, and a student whose Grit score is one standard deviation above average sets the variable *Grit* to +1. The value of the RHS of Eq. (2.2) for this student will be 0.79. A low SES student (*SES* = 1) with an average Grit score (*Grit* = 0) will set the RHS of Eq. (2.2) to 0.93. To compare the odds of persisting between these two students, we take the difference between the RHS. The result is ΔRHS = –0.14 and OR = exp(–0.14) = 0.87. This result indicates that a low SES student with a Grit score that is one standard deviation above average will have a 15% decrease in odds of persisting than a low SES student with an average Grit score. Conversely, a low SES student (*SES* = 1) with a Grit score that is one standard deviation below average (*Grit* = –1) will have a 15% increase in odds of persisting than a low SES student with an average Grit score (ΔRHS = 0.14, OR = exp(0.14) = 1.15).

In contrast, a high SES student (*SES* = 0) with a Grit score that is one standard deviation above average (*Grit* = +1) will have 33% better odds of persisting than a high SES student with an average Grit score (ΔRHS = 0.29, OR = exp(0.29) = 1.33). When comparing a high SES student (*SES* = 0) with a low SES student (*SES* = 1) with the same average Grit score (*Grit* = 0), the high SES student will have 63% better odds of persisting (ΔRHS = 0.49, OR = exp(0.49) = 1.63). Overall, we can infer that above-average Grit scores decrease the odds of persisting for low SES students, and that above-average Grit scores increase the odds of persisting for high SES students.

Now, to interpret the results in Table 2.10(a)-(c), we first notice that the beta coefficients for all three terms in all four models are positive. Then, looking at the Grit-ACTM (a) and PE-ACTM (b) interaction models, we see that the only nonsignificant term is the interaction term.

Without a statistically significant interaction term, we can interpret that this model indicates a significant, positive relationship between Grit and retention across all values of ACTM. That is, any increase in one variable while keeping the other constant will increase the odds of persisting, and any decrease in one variable while keeping the other constant will decrease the odds of persisting. The same interpretation can be made for the PE-ACTM interaction model. In contrast, the Grit-HSGPA model (c) is difficult to interpret. The result of the likelihood ratio test suggests that the Grit-HSGPA interaction model (c) is a better model than the univariate HSGPA model, but the main effect of the Grit term is nonsignificant in the interaction model. Consequently, we are not able to interpret this interaction model with confidence.

To interpret the PE-HSGPA interaction model in Table 2.10(d), we begin with the simplest interpretation by controlling for average HSGPA. We will use the PE-HSGPA interaction model for two-year retention for the following examples; see Eq. (2.3).

$$Retention \sim 1.08 + 0.24(PE) + 0.42(HSGPA) + 0.16(PE)(HSGPA) \qquad (2.3)$$

When controlling for average HSGPA ($HSGPA = 0$), a student with a PE score that is one standard deviation above average ($PE = +1$) will have 28% better odds of persisting than a student with an average PE score ($PE = 0$) (ΔRHS = 0.24 and OR = exp(0.24) = 1.28). Because $\beta_3 = 0.16$ (the coefficient of interaction term) is less than $\beta_1 = 0.24$ (the coefficient of PE), we can interpret the interaction term to affect the positive relationship between PE and retention differently when controlling for values of HSGPA that are below or above average. When controlling for below average HSGPA, the positive relationship between PE and retention becomes weaker (than OR = 1.28) and can eventually become negative. For example, when controlling for HSGPA at one standard deviation below average ($HSGPA = -1$), a student with a PE score that is one standard deviation above average ($PE = +1$) will have 8% better odds of persisting than a student with average PE score (*PE* = 0) (ΔRHS = 0.08, OR = exp(0.08) = 1.08). Furthermore, when controlling for HSGPA at two standard deviations below average (*HSGPA* = –2), a student with a PE score that is one standard deviation above average will have 8% *worse* odds of persisting than a student with average PE score (ΔRHS = –0.08, OR = exp(–0.08) = 0.92). In contrast, the positive relationship between PE and retention becomes stronger (than OR = 1.28) when students have above average HSGPA. For example, when controlling for HSGPA at one standard deviation higher than average (*HSGPA* = +1), a student with a PE score that is one standard deviation above average will have 49% better odds of persisting than a student with average PE score (ΔRHS = 0.40 and OR = exp(0.40) = 1.49). However, HSGPA was capped at 4.0, and so it is unreasonable to set *HSGPA* to one standard deviation above average.

2.5 Discussion

2.5.1 Grit's relationship to one- and two-year engineering retention

To answer our first research question, "How well does Grit predict one- and two-year engineering retention?" our data suggest that it depends. Grit is a statistically significant predictor for only two-year engineering retention (β = 0.16, OR = 1.18, p = .034), whereas PE is a significant predictor for both one-year engineering retention (β = 0.22, OR = 1.24, p = .016) and two-year engineering retention (β = 0.25, OR = 1.29, p = .001) (see Table 2.6). CI is not a significant predictor for either one-year engineering retention (β = 0.06, OR = 1.06, p = .543) or two-year engineering retention (β = 0.04, OR = 1.04, p = .646). These results suggest that PE is a more robust predictor of one- and two-year engineering retention than Grit, and that CI does not predict one- or two-year engineering retention.

These results contradict the results from Duckworth et al. (2007), the original developers of the Grit Scale. Duckworth et al. (2007) asserted that the overall Grit score was better than either CI or PE alone: “neither [CI nor PE] was consistently more predictive of outcomes than the other, and in most cases, the two together were more predictive than either alone” (p. 1091). However, our results are consistent with the results of Credé et al. (2016), who performed a meta-analysis on Grit. Based on their meta-analysis results, they did not find that Grit was a higher-order construct comprised of CI and PE. Furthermore, they criticized the original factor analytic studies as having methodological limitations. Similar to our results, they found that combining CI and PE scores into an overall Grit score actually resulted in a significant loss in the ability to predict academic performance. Consequently, they recommended that PE should be treated as a separate construct from CI to maximize PE’s utility as a predictor of performance. One should note that the studies used by Credé et al. (2016) in the meta-analysis were not specific to the undergraduate engineering population, and the meta-analysis could not always capture the effects of CI and PE on retention due to the lack of data.

Minor, further evidence for this difference between CI and PE can be seen in the correlation matrix from Table 2.5 with respect to academic performance variables (HSGPA, MG1, SEM1, CGPA1, and CGPA2). PE had larger Spearman correlations with academic performance variables ($.15 < \rho < .20$) than CI ($.05 < \rho < .11$). By combining CI and PE together for an overall Grit score, Grit had lower correlations with academic performance variables ($.12 < \rho < .16$) than PE.

This difference between CI and PE can be explained by interpreting Grit as a situated construct. That is, Grit is not useful in all cases. For example, Credé et al. (2016) described three different situations for which the usefulness of Grit could vary. First, high Grit could be more useful in difficult tasks that are well-defined and require deliberate practice (e.g., sports or musical performance), whereas high Grit could be counterproductive in tasks that are ill-defined and may require abandoning unsuccessful strategies (e.g., creative problem-solving). Second, with respect to self-regulation, high Grit may be more useful to individuals who engage in self-regulated learning because they can structure their approaches to tasks and evaluate the effort needed for such tasks, whereas students with poor self-regulation may find themselves exerting a lot of effort only to make minimal progress. Third, with respect to help-seeking, high Grit may reduce students' likelihood of help-seeking behavior, because students may spend too much time on a task before they realize they made or mistake or need help. In these examples, we can easily swap "high Grit" with "high PE" without changing the meaning of the examples. In contrast, it is not clear whether Grit can be swapped with CI. That is, the usefulness of CI is not clear in these cases. Grit may not be as domain independent as originally asserted (Duckworth et al., 2007). We recommend that future Grit studies analyze Grit's subscales in addition to Grit so that we can better understand what the CI subscale actually measures.

2.5.2 Interaction effects of moderating variables on Grit and retention

To answer our second research question, "How do student characteristics and academic performance affect the relationship between Grit and retention?" our data suggest that SES and HSGPA had statistically significant moderating effects on retention when included with Grit and PE, respectively. Specifically, the Grit-SES interaction model had a negative relationship between Grit and retention for low SES students, whereas the model had a positive relationship between Grit and retention for high SES students. In comparison, the PE-HSGPA interaction model had a weak positive or negative relationship between PE and retention when controlling for low HSGPA, whereas the model had a strong positive relationship between PE and retention when controlling for high HSGPA.

A reasonable explanation for the Grit-SES interaction model is that low SES students need more than high Grit to help them persist in engineering. We see additional evidence from our results in Table 2.4 regarding differences based on SES. For example, we found that low and high SES students had similar average Grit scores, but low SES students had lower average MG1, SEM1, CGPA1, and CGPA2 than high SES students. We can interpret this difference in college performance to suggest that, on average, low SES students will perform worse than high SES students in college. Consequently, the evidence suggests that improving Grit alone will not help students persist in engineering.

For the PE-HSGPA interaction model, one explanation for the weak positive or negative relationship between PE and retention when controlling for low HSGPA is the ceiling effect of HSGPA. The average HSGPA was 3.90 for our population with a standard deviation of 0.17, and the ceiling HSGPA was 4.0 (from Table 2.5). Looking deeper at our population, there were 501 students that had 4.0 HSGPA with an additional 80 students who had above average HSGPA. Overall, 70% of students had above average HSGPA. Furthermore, the univariate HSGPA model had odds ratios of 1.49 and 1.50 for one- and two-year retention, respectively (from Table 2.6). These odds ratios imply that students with below average HSGPA had low odds of persisting. With many fewer low HSGPA students than high HSGPA students, it is not unreasonable that the model infers a negative relationship between PE and retention when controlling for low HSGPA if several students did not persist with above average PE scores but below average HSGPA. This interpretation suggests that improving PE will not help low HSGPA students persist in engineering.

On the flip side, the strong positive relationship between PE and retention when controlling for high HSGPA suggests that high HSGPA students with high PE scores are more likely to persist. This interpretation is not surprising because we expect students with high HSGPA to academically outperform students with low HSGPA in college. Similarly, we expect students with high PE scores to academically outperform students with low PE. Our correlation matrix in Table 2.5 supports this claim because HSGPA had correlations between .31 and .41 for MG1, SEM1, CGPA1, and CGPA2, and PE had correlations between .15 and .20 for the same variables.

2.5.3 Grit models have low predictive power

Our data suggest we should not use Grit or PE to predict engineering retention because these measures lack predictive power. According to the values of Nagelkerke's R^2 (see Table 2.7), Grit accounts for 1% of the variance in the univariate Grit model for one- and two-year retention, whereas PE accounts for 1% and 2% of the variance in the univariate PE model for one- and two-year retention, respectively. Furthermore, based on the classification tables (see Table 2.8), the univariate PE models for one- and two-year engineering retention have true positive rates (TPR) of about 50% and false positive rates (FPR) of about 40%. We can interpret these values to mean that we would correctly identify 50% of potential departers but misidentify 40% of persisters as potential departers. In comparison, the univariate CGPA1 models for one- and two-year retention – the models with the highest Nagelkerke's R^2 values in our analysis (.33 and .36, respectively) – have TPRs of about 68% and FPRs of about 25%. However, using PE has an advantage over using CGPA1: PE scores can be obtained early in a students' undergraduate career, whereas CGPA1 will take at least one academic year to obtain, after which many students will have already departed. The disadvantage of using the univariate PE model is that it results in higher FPR than the univariate CGPA1 model.

In comparison, Hall et al. (2015) used multivariate, multinomial logistic regression in their two-year engineering retention study (*n* = 256) to compare persisters with departers who left in good standing (LGS) and departers who left in poor standing (LPS). They defined retention as "the completion of the first four semesters in good standing in the engineering program" (*p*. 174). Their definition was similar to our definition of two-year retention expect for our criterion of continuous enrollment. In their study, the two-year retention rate was 40.2%. Their regression model input all the predictor variables at once such as Conscientiousness, SAT math, and HSGPA, but none of them were academic performance variables from college. Their model had a Nagelkerke's R^2 of .284. They do not report a classification table, but they mentioned that their logistic model correctly predicted persisting students (69.9%), LPS students (64.7%), and LGS students (40.0%).

We also compared the regression results from Hall et al. (2015). We can use their results for Conscientiousness as a proxy for Grit (and its subscales) because the meta-analysis by Credé et al. (2016) reported that Grit, CI, and PE were highly correlated with Conscientiousness (ρ = .84, ρ = .61, and ρ = .83, respectively). We can use their results for SAT math as a proxy for ACTM because we can use a concordance table to convert one score to the other (Dorans, 1999). In the results of Hall et al. for LPS students in their sample, Conscientiousness (OR = .446, p < .001) and HSGPA (OR = .433, p < .001) were significant predictors of retention. We interpreted these low OR values to mean that students with higher Conscientiousness and HSGPA have lower odds of departing in poor academic standing. Furthermore, in their results for LGS students in their sample, SAT math (OR = .614, p = .011) was a significant predictor of retention. These results were consistent with our results in that Grit, ACTM, and HSGPA were all significant predictors of two-year engineering retention. In addition, Hall et al. (2015) reported that Conscientiousness did not have a statistically significant correlation to SAT math ($r = .08$, $p > .05$) or HSGPA ($r = .05$, $p > .05$). In contrast to their results, we found a negative correlation between ACTM and both Grit ($\rho = –.10$, $p < .05$) and CI ($\rho = –.14$, $p < .001$) but not PE ($\rho = –.03$, $p > .05$). Furthermore, we found a positive correlation between HSGPA and both Grit ($\rho = .12$, $p < .001$) and PE ($\rho = .16$, $p < .001$), but not CI ($\rho = .05$, $p > .05$). We note that Hall et al. (2015) used Pearson correlations since they report the r statistic (though their methodology is not mentioned explicitly), whereas we used Spearman correlations, or ρ (because our variables did not follow a normal distribution).

2.5.4 Comparing Grit with other variables

Our study used ACTM, whereas other studies may have used SAT scores. We treated SAT and ACT scores as equivalent because we could use a concordance table to convert one score to the other (Dorans, 1999). Our correlation results showed that ACTM had a weak negative correlation with Grit ($\rho = –.10$) and CI ($\rho = –.14$) (see Table 2.5). In comparison, Jaeger et al. (2010) found no significant correlation between Grit and SAT scores for first-year engineering students, whereas Duckworth et al. (2007) did find negative correlations for undergraduate psychology students ($r = –.20$). However, these studies used total SAT scores rather than using only SAT math. We also found that Grit had a weak positive correlation with CGPA1 ($\rho = .16$) and CGPA2 ($\rho = .13$). This result is consistent with Chen et al. (2015) in that students with higher Grit also had higher GPA, but they used a series of one-way ANOVA as their statistical inference based different ranges of GPA (4.0–3.5, 3.49–3.0, 2.99–2.5, and 2.49–2.0). Duckworth et al. (2007) also found that Grit was positively correlated with GPA for undergraduate psychology students (*r* = .25). However, we note that Chen et al. (2015) and Duckworth et al. (2007) combined first-year students with all other academic levels (i.e., sophomores and above) in their analysis.

Also, in Table 2.6 we see that all academic performance variables were statistically significant predictors of one- and two-year engineering retention but both gender and SES were not. When comparing with pre-college performance variables, for one-year engineering retention, ACTM (OR = 1.31) and HSGPA (OR = 1.49) had a larger odds ratio than PE (OR = 1.24). For two-year retention, HSGPA had the largest odds ratio of 1.50, followed by PE (OR = 1.29), ACTM (OR = 1.28), and Grit (OR = 1.18). Furthermore, when comparing with college performance variables (i.e., MG1, SEM1, CGPA1, and CGPA2), all college performance variables had larger OR than Grit, PE, ACTM, and HSGPA according to OR and Nagelkerke's R^2 (see Table 2.7). Among these variables, CGPA1 was the best predictor of retention for one- and two-year retention with an OR of 4.40 and 3.75, respectively. This result was not surprising because our definition of retention had an academic standing criterion based on GPA.

With respect to gender differences in Table 2.3, we found that in our sample, female students had higher Grit (*M* = 3.63, *SD* = 0.51) than male students (*M* = 3.54, *SD* = 0.53). Female and male students had similar PE, but female students had higher CI (*M* = 3.28, *SD* = 0.71) than male students (*M* = 3.17, *SD* = 0.71). Our results agree with Jaeger et al. (2010) in that Grit and CI were higher for women than men, but their study did not provide any numerical evidence. In contrast, Chen et al. (2015) found no significant difference in Grit scores between female and male students, but they did not analyze Grit's subscales separately. In the meta-analysis by Credé et al. (2016), gender had true score correlations that were close to zero with Grit, CI, and PE (ρ = .05, ρ = .03, and ρ = .03, respectively).

With respect to SES differences in Table 2.4, we found that low SES students had higher CI scores (*M* = 3.33, *SD* = 0.72) than high SES students (*M* = 3.17, 0.71), but there was no difference between their Grit and PE. Chen et al. (2015) found no differences in Grit based on students' SES. They defined SES using students' perception of their family's financial well-being, whereas we defined SES using family income quartiles based on students' FAFSA. However, we again note that their analysis combined first-year students with all other academic levels.

2.5.5 Limitations

Our study was limited to one large public university in the West, and so we caution against the generalization of our results. We specifically targeted students in the college of engineering at this university, but perhaps there were certain facets about our population that we did not consider. For example, we did not include pre-engineering students in our sample because this institution placed them in the college of arts and science. Furthermore, we excluded students who did not have complete data sets. This exclusion resulted in removing many international students. Also, this institution had a predominantly White population (69% in our sample). The one- and two-year retention rates for our sample were 82.4% and 74.1%, respectively. Other institutions may have a much lower retention rate, for example, the two-year retention rate of 40.2% reported by Hall et al. (2015). We recommend that future studies include a larger, more diverse sample of students from various institutions and engineering programs.

Another limitation was the ceiling effect with HSGPA. The mean HSGPA was 3.90 on a 4.0 scale with a standard deviation of 0.17. One standard deviation increase in HSGPA would result in a HSGPA greater than 4.0. Furthermore, one standard deviation decrease in HSGPA would be 3.73, which is still a very high grade. This ceiling effect and lack of variance reduce the effectiveness of HSGPA in identifying potential departers. We previously mentioned in the Methods section that the HSGPA we obtained was capped at 4.0 even if students' weighted HSGPAs were above 4.0. Consequently, we lost the variance that students' weighted HSGPA may have offered. However, we analyzed ACTM and other college performance variables to mitigate this limitation.

Another limitation was our definition of retention. Our definition included the criteria of continuous enrollment and good academic standing. With respect to continuous enrollment, in reality, some engineering students drop out temporarily for health and financial reasons, and these students may persist in engineering at a later time. In our sample, these students would be categorized as departers. However, only five students were categorized as departers because they had unexplainable gap semesters, even though they were in good academic standing. Two of these students had a gap semester during their first year, whereas the other three had a gap semester during their second year. These students comprise less than one percent of our sample. Therefore, we believe this limitation had minimal impact on the interpretation of our results. With respect to good academic standing, the GPA policy for continuation was 2.25 at this institution. Other institutions may have different GPA policies. In our sample, only one student demonstrated academic recovery from poor academic standing. Other students who maintained poor academic standing were dropped for one semester or dropped from the institution entirely. At other institutions, students may have recovered from poor academic standing with a more lenient GPA policy. Therefore, this criterion for good academic standing adds to the limitation of studying only one institution.

With respect to our findings on SES, a major limitation was that students who did not file FAFSA were categorized as part of the highest SES group. We adopted this categorization based on how the institutional database categorized SES information. In reality, some low SES students may not have been aware of financial aid resources such as FAFSA and may have failed to submit a financial aid application. As a consequence, we caution against placing unwarranted weight on our findings regarding SES. However, this limitation does not contradict our interpretation that above-average Grit scores decrease the odds of persisting for low SES students, and that above-average Grit scores increase the odds of persisting for high SES students. According to the current interpretation, the inclusion of low SES students in the high SES group should lower the odds of persisting for students in the high SES group with above-average Grit scores (i.e., lower the odds ratio of Grit for the high SES group). In contrast, if low SES students were properly placed into the low SES group, above-average Grit scores would further decrease the odds of persisting for low SES students. Therefore, our finding on SES is conservative as is.

Another limitation of our findings is that we set our level of statistical significance at .05, despite the large number of repeated tests and the large sample size. However, we addressed this limitation by interpreting our statistical results with values of Nagelkerke's R^2, an indicator of predictive power. For example, though Grit and PE were statistically significant predictors of retention, they have low predictive power.

Last, we did not test any noncognitive variables other than Grit to predict retention. Other noncognitive variables may have helped us understand what CI is correlated to, similar to how

Conscientiousness is highly correlated with Grit. However, the goal of our study was to determine whether Grit was a significant predictor of retention as it was for the original study by Duckworth et al. (2007). Credé et al. (2016) note that Grit predicts retention approximately as well as traditional predictors of retention such as SAT scores and high school grades but not as well as some other noncognitive predictors such as academic self-efficacy, academic-related skills, institutional attachment, and social adjustment.

2.6 Conclusion

We used binary logistic regression to predict whether students would persist in engineering after one and two years based on Grit, student characteristics, and academic performance. We defined retention as continuous enrollment at the university in the college of engineering while maintaining good academic standing.

We found that students with higher Grit scores had higher odds of persisting in engineering after two years but not after one year. Perseverance of Effort (PE), one of Grit's subscales, was found to be a better predictor than Grit for one- and two-year engineering retention, whereas Consistency of Interest (CI), Grit's other subscale, was not a significant predictor of retention in any regression analyses. However, Grit and PE had low predictive power according to values of Nagelkerke's R^2 (ranging between .01 and .02). In comparison, first semester math grade (MG1), first-semester GPA (SEM1), first-year cumulative GPA (CGPA1), and second-year cumulative GPA (CGPA2) were stronger predictors of retention, and their univariate regression models had larger values of Nagelkerke's R^2 (ranging between .20 and 0.36), indicating stronger predictive power. Overall, CGPA1 was the strongest single predictor of one- and two-year engineering retention.

When exploring how student characteristics and academic performance variables affected the relationship between Grit and retention, we found that students with high socioeconomic status with high Grit scores had increased odds of persisting after two-years, whereas the opposite effect occurred for students with low socioeconomic status. That is, students with low socioeconomic status had reduced odds of persisting after two-years if they had high Grit scores. Also, we found that the relationship between PE and retention was slightly positive (and became negative) when controlling for below average HSGPA, whereas the relationship was positive (and grew stronger) when controlling for above average HSGPA.

According to Duckworth et al. (2007), Grit, an equally weighted combination of CI and PE together, should be a better predictor of success than either of its subscales alone. However, our results suggested that combining CI and PE to produce an overall Grit score reduced the ability of Grit to predict retention when compared with PE alone. In other words, the utility of Grit to predict retention lay in PE alone. Credé et al. (2016) reported a similar finding with respect to PE and academic performance: “[PE] is a much better predictor of performance than either [CI] or overall grit and should therefore probably be treated as a construct that is largely distinct from [CI] to maximize its utility” (p. 11). We recommend that future Grit studies also test the subscales individually in addition to overall Grit scores to better understand the utility of CI and PE – CI in particular.

Though PE was statistically significant in our regression models, we caution against using PE to reliably identify potential engineering departers. According to our classification tables, the univariate PE models had true positive rates (TPR) of about 50% and false positive rates (FPR) of about 40% with Nagelkerke’s R^2 values between .01 and .02 for one- and two-year engineering retention, respectively. In comparison, the univariate CGPA1 models had TPRs of about 68% and FPRs of about 25% with Nagelkerke's R^2 values of .33 and .36 for one- and two-year engineering retention, respectively.

In conclusion, Grit scores should not be used to determine whether students will persist in engineering for three reasons. First, PE is a better predictor of retention than Grit and is considered to be similar Conscientiousness (Credé et al., 2016). Consequently, researchers should consider using Conscientiousness over Grit because Conscientiousness has more historically validated research. Second, CI was not a significant predictor of retention in any of the regression analyses. We recommend that future Grit studies analyze Grit's subscales in addition to Grit so that we can better understand what the CI subscale actually measures. Third, though our results are statistically significant, Nagelkerke's R^2 values and classification tables reveal that univariate PE models have low predictive power. Therefore, we caution against using the Grit Scale for the purposes of predicting engineering retention.

CHAPTER 3

ENGINEERING SURVIVORS: ENGINEERING STUDENTS WHO PERSIST THROUGH ACADEMIC FAILURES

3.1 Introduction

In the United States, engineering programs suffer from low retention rates and correspondingly low degree attainment rates. For first-time, full-time students who entered engineering programs in 2007, the average five-year attainment rate for engineering degrees was only 49.7% (Grose, 2016). However, this attainment rate varied greatly among programs, with the highest rate at 97.3% and the lowest rate at 4.0%. Furthermore, engineering programs receive few transfer students from other majors (Ohland et al. 2008). As a consequence, the multitude of students who leave engineering are only partially replaced by transfer students.

Researchers have previously identified reasons for why students leave engineering. We refer to students who leave an engineering major as *departers*: they leave the engineering program or leave the university altogether. We refer to students who stay in engineering as *persisters*. Haag, Hubele, Garcia, and McBeath (2007) asked engineering departers to compare their new majors with their old engineering major. Departers felt that they lacked adequate high school preparation for the engineering major, felt that engineering faculty were unapproachable and provided inadequate help with academics or advising, and experienced low morale due to the competitive culture and lack of peer support in engineering. In another study, Marra, Rodgers, Shen, and Bogue (2012) surveyed departers to identify a set of factors that strongly influenced their decisions to leave. These factors were curriculum difficulty, poor teaching and advising, and lack of a sense of belonging. Furthermore, Meyer and Marx (2014) interviewed four students who had recently departed their engineering programs. They asked the students to explain their reasons for departure and to describe their experiences. These departers experienced poor academic performance, felt unprepared for the demands of the engineering program, had difficulty fitting into engineering, and faced disappointment with engineering advising. Overall, we see similar themes of perceived academic difficulty, chilly climates, and poor teaching and advising.

However, the problems that departers experience are not unique to them; persisters experience the same problems. Students' top four reasons to leave science, math, and engineering (SME) majors were loss of interest in the discipline, interest gained in a non-SME major, poor teaching by SME faculty, and feeling overwhelmed by the pace and load of course demands (Seymour & Hewitt, 2000). However, these factors were also cited as concerns by 31% to 74% of persisters (Seymour & Hewitt, 2000). Two additional concerns that were shared by over one-third of both departers and persisters were 1) inadequacies in the provision of advising or counseling and 2) insufficient high school preparation. Despite similar experiences, there were no significant differences in the academic performance of departers and persisters: the average grade-point-average (GPA) of departers was 3.0, and the average GPA of persisters was 3.15 (Seymour & Hewitt, 2000). Marra, Rodgers, Shen, and Bogue (2012) also found no significant differences between departers and persisters with respect to entering SAT math scores, SAT verbal scores, and their cumulative GPA. At a high-level view, we see that the experiences of departers and persisters are not so different.

However, when considering a low-level view, we can explain why persisters and departers have no significant difference in academic performance. That is, these studies combined low GPA students with high GPA students, effectively averaging students' GPA. For example, low GPA students are forced to depart by institutional probation and drop policies, whereas high GPA students may depart because they lose interest in engineering and can succeed in other majors. For persisters, low GPA students persist by improving their academic performance or by returning to engineering programs after probation and drop, whereas high GPA students persist because they did not intend to leave in the first place. Based on this argument, when we average the two extremes, it is reasonable that the average departer's GPA is not significantly different from the average persister's GPA. There is something about these low GPA persisters that drives them to persist (rather than depart) despite academic failures. In our study, we focus on engineering persisters who have failed a required technical course, as representatives of low GPA persisters. We suspect that these persisters experience failure differently from departers.

To understand this difference in experience between departers and persisters, our study complements the qualitative study by Meyer and Marx (2014), who explored the experiences of engineering departers. In contrast, our qualitative study explores the experiences of engineering persisters who have faced academic failures. Taken together, we may better understand the differences between departers and persisters.

3.2 Background

Though many studies focus on engineering retention and attrition, few studies focus on how students persist despite failing. One study surveyed and interviewed engineering students to explore the effects of barrier courses (i.e., Calculus I & II, Physics I & II, and Statics) on students' decisions to persist (Suresh, 2006). Persisting students were divided into three groups for comparison. "Sailers" were students with A and B grades who never failed a barrier course:

they “sailed through” their courses. “Plodders” were students with B and C grades who may or may not have repeated a barrier course. “Struggling persisters” were students with Cs, Ds, Fs, Ws (withdrawals), and Rs (resignations) who had repeated one or more barrier courses one or more times.

Based on survey data, all three groups had similar reasons for choosing engineering as their major in that they expressed interest in engineering and had aptitude for science and math during high school. However, struggling persisters believed that professors intentionally made courses difficult to “weed out” students, whereas sailers did not. Struggling persisters also tended to believe that engineering was the survival of the fittest, whereas sailers did not. Plodders were somewhat between the two perspectives but leaned towards agreement with struggling persisters. Furthermore, based on interview data, all three groups persisted in engineering because they could not see themselves giving up, and that they did not know of any other major they would rather pursue. Suresh (2006) concluded that the “single most important factor that played a role in persistence was student determination, and to not quit when they encountered difficulties” (p. 233). This determination was common to all persisting students, across all levels of academic performance. Other important factors included support and encouragement from family, faculty, or administrators. Suresh (2006) found that “[o]ften it was this one person [faculty or administrative staff] who had the power to sway their [students’] decision and convince them to keep persisting” (p. 233).

These findings from Suresh (2006) explain why students persist despite facing academic difficulties. More specifically, we see the importance of engineering students’ determination when facing difficulties and the influence of strong support from family, faculty, or administrators. We note that the strong support of faculty or administrators differs significantly from the experiences of the students interviewed by Meyer and Marx (2014), who felt unsupported by their academic advisers. Our present study builds on the study by Suresh (2006) in that we explore the experiences of students who resemble plodders and struggling persisters. That is, we take a deeper look into students' academic failure experiences.

In another study of engineering persisters, McCain, Fleming, Williams, and Engerman (2007) interviewed 60 engineering students and the role of doggedness in degree completion. McCain et al. (2007) operationalized *doggedness* as "factors and characteristics that show a high level of commitment to completing a degree in engineering, an intention towards perseverance for its own sake, and varying degrees of enjoyment and satisfaction" (p. 3). Based on student interviews, they identified three different kinds of students with doggedness: unyielding persisters, intense goal setters, and economic rationalizers. *Unyielding persisters* were students who believed that pursuing an engineering degree was what they were supposed to do. *Intense goal setters* were students who persisted in engineering for the sake of completing what they had already started. *Economic rationalizers* were students who persisted in engineering because of the financial costs of switching majors. However, there is no evidence that these students had experienced academic failures.

Students who experience academic failure typically feel ashamed. Turner, Husman, and Schallert (2002) examined the emotion of shame to explore the relationship between students' goals and emotions. More specifically, this study focused on upper-level psychology students' experience with shame when performing poorly in a difficult psychopharmacology course. The researchers categorized students as either shame-resilient or shame-nonresilient. They identified three characteristics that were important for shame-resilient students: "(a) highly extrinsically motivated, (b) had certainty regarding their sense of academic competence, and (c) perceived that a good grade was instrumental to future academic goals" (p. 84). Furthermore, they described the behavior of these students as having "the tendency to bounce back after a shame reaction with increased motivated behavior that included and resulted in relatively higher levels of academic achievement" (p. 84). Students perceived that their first exam grade was unacceptable and felt a need to perform better.

In contrast, Turner et al. (2002) described shame-nonresilient students as ambivalent, confused, and conflicted. These students questioned their ability to raise their grade after performing poorly on the first exam. They tended to use surface-level strategies for studying and learning, and they continued to use the same unsuccessful strategies they had used for the first exam. Some students resigned to studying less because they were unmotivated to study even though they knew they should. In addition, Turner et al. (2002) described one student who was an exception because she transitioned from shame-nonresilient to shame-resilient. The researchers attribute this student's transition to two factors: 1) she received help from a successful classmate and friend, and 2) she applied the knowledge from a class that taught self-regulation theories and strategies that she was taking concurrently.

The findings from Turner et al. (2002) show how academic failure induces shame-resilient and shame-nonresilient behaviors, and how students can stay shame-nonresilient or become shame-resilient. However, this study focused on advanced psychology students who had already persisted to the later stages of their program (i.e., juniors and seniors). These students were already "survivors" who were less at-risk of leaving their program. Furthermore, we do not know if these responses to shame apply to different student populations (e.g., first-year students or engineering students). Our present study builds on the study by Turner et al. (2002) in that we focus on engineering students' experience with academic failure.

As mentioned before, there is a dearth of literature on the persistence of engineering students despite their academic failure. Our study contributes to this literature by extending Suresh's study of engineering persisters (2006), that is, by exploring the failure experiences of students who resemble plodders and struggling persisters in more detail. Our research question is, "In what variety of ways do persisting engineering students experience academic failures?" Academic failure includes low exam scores, poor course grades, and atrocious semesters.

3.3 Methods

In this study, we explored students' experiences with academic failure in engineering. We took a social constructivist stance. This epistemological stance posits that people construct their own truths and realities through their personal experiences, and that we can understand people's constructed realities only through interaction with them. Consistent with this stance, we chose phenomenography as our qualitative research method, because phenomenography is used to investigate people's understanding of various phenomena, concepts, and principles (Marton, 1986). In the present study, the phenomenon is experiencing academic failure in an engineering program.

There are two main traditions of phenomenography: pure phenomenography, which was developed by Swedish researchers (Marton, 1986), and developmental phenomenography, which was developed by Australian researchers (Bowden & Green, 2005). The purpose of pure phenomenography is to understand students' conceptions of reality such as forces and optics (Marton, 1986). Pure phenomenography uses problem-solving interviews as the main source of data. During data analysis, researchers analyze across excerpts from interview transcripts to categorize students' conceptions of reality. In contrast, the purpose of developmental phenomenography is to understand the depth of an experience (Bowden & Green, 2005). Developmental phenomenography uses semi-structured interviews to have the flexibility to probe deeper into people's experiences of a phenomenon. During data analysis, researchers analyze across individuals (represented by whole transcripts) to categorize their experience. We followed the methods of developmental phenomenography because we were interested in students' depth of experience with academic failure rather than their conceptions of academic failure.

Marton (1986) asserted that each phenomenon, concept, or principle could be understood only "*in a limited number of qualitatively different ways*" (p. 31). As a result, the outcome of phenomenography is a category of descriptions that describe the qualitatively different ways that people experience a phenomenon. These categories are often hierarchical by an increasingly comprehensive awareness or experience. When conducting phenomenography, researchers do not analyze data with a particular theory in mind because the usage of theories biases the researchers' interpretation of people's experiences. Rather, the data analysis methods often resemble grounded theory, because the categories must be thoroughly grounded in the data.

3.3.1 Data collection

Early in the spring of 2015, we mass emailed 6771 undergraduate students in the college of engineering at a large public university. The email invited students to participate in one-hour, semi-structured interviews and offered a $10 compensation for their time. The email specified that we sought students who were persisting in engineering after having earned a D or F in a required technical course (e.g., physics, math, computer science, or engineering). We chose this selection criterion to capture the plodders and struggling persisters who had failed and retaken barrier courses in the study by Suresh (2006). Also, failure in these courses is serious because it can prevent students from completing an engineering degree in four years. For example, Calculus I is a prerequisite for Physics I, which in turn is a prerequisite for Engineering Statics. A student who fails Calculus I must repeat that course and therefore, delay taking subsequent required courses. In addition, some required courses may be offered only once per year. These situations further delay degree attainment for students who fail prerequisite courses. With such dire consequences, we believed that students who had failed a required course would provide rich descriptions of experiencing academic failure.

Another reason for choosing this selection criterion was to limit the number of participants so that scheduling interviews and data analysis would be more manageable. Most phenomenographers interview between 20 and 30 participants to ensure enough variations in ways of experiencing the phenomenon and to limit the number of participants for data management (Bowden & Green, 2005). In recent phenomenographic studies in engineering education, the number of interviews is close to this range as well (Zoltowski, Oakes, & Cardella, 2012; Fila & Purzer, 2017). Each of these studies used 33 interviews. If we were to include students who had simply failed an exam, there would be too many possible participants. In addition, not all these participants would have treated a low exam grade as an academic failure if they had improved their academic performance by the end of the course. By limiting our population to students who had failed a required course, we would be guaranteed to capture students' experiences that included multiple exam failures and ultimately a failed course.

Students replied to the email solicitation using an embedded link that led them to a Google Form. On this form, students entered their name, email, and school ID. We received 76 responses through the Google Form. However, only 26 students maintained contact through follow-up emails and attended their scheduled interview appointments. Consent forms were emailed to the participants before their appointment, and additional consent forms were offered in-person in case the participant did not read or complete it beforehand. These consent forms were collected at the beginning of their interview. The interviews took place near the end of the spring semester through April and May 2015. We note that these students self-reported that they were persisting in engineering at the time of the interviews. We did not track whether these students stayed in engineering until degree attainment.

In developing the interview protocol, we asked questions consistent with developmental phenomenography (Bowden & Green, 2005). For example, we asked, "What are some failures you've experienced in the past?" "What have you actually done in the past regarding your failures?" and "How would you recommend someone to go through failure well?" We also asked questions that were motivated by theories such as mindset theory (Dweck, 2006), goal orientation theory (Kaplan & Maehr, 2007), and theory of grit (Duckworth, Peterson, Matthews, & Kelly, 2007).

According to mindset theory, students with a *growth mindset* believe that intelligence can improve with effort, whereas students with a *fixed mindset* believe that intelligence cannot be changed (Dweck, 2006). We believed that mindset theory would help us understand how students viewed effort within their failure experience. For example, during the interviews, we asked, "How much do you agree with the following phrase?: I believe I am able to achieve anything I want if I put in the time and effort." Furthermore, Dweck (1986) found that students with the growth mindset adopt mastery goal orientations, whereas students with the fixed mindset adopt performance goal orientations. According to goal orientation theory, students with a *mastery goal orientation* focus on learning, understanding, and developing skills, whereas students with a *performance goal orientation* focus on grades, create impressions of high ability, and avoid impressions of low ability (Kaplan & Maehr, 2007). We believed that goal orientation theory would help us understand how students viewed grades and learning within their failure experience. For example, motivated by goal orientation theory, we asked, “What kind of goals do you set for yourself?” and “What happens when you don’t meet these goals?”

Though unrelated to mindset and goal orientation theories, we also believed that the theory of grit would help us understand how students persist despite failure. Duckworth et al. (2007) defined *grit* as “perseverance and passion for long-term goals” and “entails working strenuously toward challenges, maintaining effort and interest over years despite failure, adversity, and plateaus in progress” (Duckworth et al., 2007, pp. 1087–1088). For example, some grit-related questions were, “How much does failure discourage you?” and “What would you do to evaluate your failures?”

These theory-driven questions were intended to help us probe deeper into how students conceptualized their failure experiences. Following the principles of developmental phenomenography, however, we did not use these theories to frame our data analysis. The full interview protocol can be found in Appendix A.

All interviews were audio-recorded and later transcribed verbatim. The lengths of the interview ranged from 32 to 92 minutes, with a median length of 66 minutes. I conducted all the interviews and transcribed 17 of them. The rest of the transcriptions were completed with the help of undergraduate research assistants. This present study was approved by the local Institutional Review Board (IRB#15196).

3.3.2 Participants

All demographic information about participants was self-reported; see Table 3.1. Academic levels ranged from first-year to fifth-year. Among traditional aged students, there were three first-year students, six second-year students, six third-year students, six fourth-year students, and two fifth-year students. Additionally, there were three non-traditional students who were older than 23 years of age: one second-year student and two fourth-year students. Out of 15 engineering majors offered by the college of engineering, 12 were represented by at least one student. Overall, there were nine females and 17 males. Among them, there were seven international students (one Black, one Hispanic, and five Asians) and 19 domestic students (one Black, one Hispanic, five Asian, and 12 White). Though female and international students were overrepresented, overrepresentation was not a concern since the purpose of phenomenography is to describe participants' varied experiences rather than to generalize an experience across the population.

3.3.3 Data analysis

Initially, two undergraduates and I analyzed the first five transcripts to familiarize ourselves with the data. We presented preliminary results from this analysis in a previous conference paper (Choi, 2016). Soon after, the undergraduate assistants were unable to continue with the analysis, but we partnered with another institution and received assistance from two first-year doctoral students through an institutional program. With these doctoral students, I analyzed an additional ten transcripts for a total of 15 transcripts. However, these doctoral students moved onto different projects at their institution after the program ended. From then on, I used the first 15 transcripts to construct categories that were to be refined using the remaining 11 transcripts; this practice is

Table 3.1: Self-reported demographics of interview participants listed in the order in which they were interviewed

Pseudonym	Academic Level (year)	Engineering Major	Gender	Race/Ethnicity
Adam	4	Aerospace	Male	Asian
Ben	4	Civil	Male	White
Cathy	2	Electrical	Female	Asian**
Dan	4	Aerospace	Male	Black
Evan	2	Civil	Male	Hispanic**
Felix*	2	Industrial	Male	White
Greg	2	Chemical	Male	White
Hugo	3	Computer	Male	Asian**
Ivan	3	Computer	Male	White
Jane	3	Computer	Female	Asian
Ken	2	Mechanical	Male	Asian**
Lucy	4	General	Female	White
Max	5	Civil	Male	White
Nancy	1	Chemical	Female	White
Owen	4	Computer Science***	Male	Asian
Pam	1	Mechanical	Female	Black**
Quinn	3	Agricultural	Female	White
Ruth	4	Materials Science	Female	Asian
Simon	1	Aerospace	Male	White
Tim*	4	Aerospace	Male	Asian**
Ulysses	3	General	Male	Hispanic
Vincent	5	Mechanical	Male	White
Wayne	3	Chemical	Male	White
Xavier	2	Computer	Male	Asian**
Yvonne*	4	Nuclear	Female	White
Zelda	2	Civil	Female	Asian

Note: * denotes a non-traditional student (i.e., above at least 23 years of age)
** denotes an international student
*** Computer Science is a part of the College of Engineering at this institution

common in phenomenography (Bowden & Green, 2005). I coded and analyzed the remaining 11 transcripts alone. Though most of the analysis and interpretation were made by me as an individual researcher, I took steps to promote trustworthiness; see *3.3.4 Trustworthiness*.

Sjöström and Dahlgren (2002) describe seven steps of phenomenography: familiarization, compilation, condensation, grouping, comparison, naming, and contrastive comparison. During *familiarization*, the researcher becomes familiar with the transcripts by reading through them and correcting errors in the transcripts. During *compilation*, the researcher compiles answers from participants to a certain question. During *condensation*, the researcher reduces individual answers by identifying key parts of long passages. During *grouping*, the researcher makes preliminary groups or categories based on similar answers. During *comparison*, the researcher establishes borders between categories. During *naming*, the researcher names categories to capture their essence. During *contrastive comparison*, the researcher describes the uniqueness of each category as well as the relationship between categories. We explain our methods according to these steps.

During *familiarization,* I transcribed 17 transcripts. One undergraduate research assistant transcribed the remaining nine transcripts. The two undergraduate research assistants helped only for transcribing and correcting errors in transcriptions. For each transcript, I wrote memos to summarize the large amount of data. For example, the memos contained information regarding students' general experience with academic failure and their general attitudes toward their experience.

During *compilation*, we did not compile answers from participants to certain interview questions, because students shared failure experiences during different questions in their interview. As a consequence, the two first-year doctoral students and I used Structural Coding for the first round of coding to code long excerpts within transcripts pertaining to the students' specific experiences with academic failure. For example, we coded long passages that captured experiences of receiving poor exam scores, earning poor course grades, and experiencing atrocious semesters. Structural codes were ideal for our analysis as these codes were designed to be applied to large chunks of data pertaining to a specific research question (Saldaña, 2013). The two doctoral students only helped during structural coding and to help bracket bias from the analysis. For example, during the discussion of what passages should be coded, we decided to remove passages that were related to a hypothetical failure and not an actual academic failure, because we wanted to analyze students' actual failure experiences. Furthermore, though students' explanation of certain situations had potential to be related to their actual failure experiences, we chose to avoid making these inferences unless students explicitly connected these situations with their failure experience.

During *condensation*, I, by myself, conducted a second round of coding to code key parts of the long passages obtained during structural coding. The key parts were when the academic failure occurred, what the failure was, and how students responded to the failure. I chose to discard long passages that did not contain all three key parts of students' failure experiences. During *grouping*, I made preliminary groups based on similarities between cases according to how students perceived failure and how students responded to failure. During *naming*, I assigned preliminary names for each category. During *contrastive comparison*, I defined critical variations that separated one category from another. That is, the critical variation of one category would not be used to describe another category. Consistent with developmental phenomenography, the memos from the familiarization step were used to interpret specific failure experiences within the context of the student who experienced the failure (Bowden & Green, 2005). In pure phenomenography, these failure experiences would be interpreted in a decontextualized way (Marton, 1986).

We used a multiple iteration process for the following steps: condensation, grouping, naming, and contrastive comparison. During these iterations, I coded for additional details to help refine categories by sharpening the boundaries that comprised critical variations. For example, I observed that certain students succeeded based on their response to failure, whereas others failed despite their response to failure. As a consequence, I included the outcomes of students' responses as part of understanding students' failure experience. Iterations were repeated until all failure experiences, which were obtained during the condensation step, were captured by the categories of descriptions, and until nothing new emerged from additional iterations.

3.3.4 Trustworthiness

We used a qualitative research methodology, phenomenography, that was aligned with our ontological and epistemological stance, social constructivism. That is, we used phenomenography to illuminate the variety of ways students experience academic failure. We used semi-structured interviews to obtain descriptions of students' socially constructed experiences with academic failure, and we interpreted these experiences as truths of their reality.

During recruitment, following the methodology of phenomenography, we solicited the entire undergraduate engineering population at the institution (where the study took place) to capture a wide variety of academic failure experiences. We succeeded in recruiting a diverse pool of participants that included male and female students, domestic and international students, traditional and non-traditional students, and students from a variety of engineering majors; see

Table 3.1. Our sample was sufficient to explore the research question, because after creating preliminary categories using the first 15 transcripts, no new categories emerged from the remaining 11 transcripts.

To ensure the consistency of data collection, I conducted all 26 student interviews and personally transcribed 17 of them. Though various theories were used to inform our interview protocol, these theories were used only to develop questions that probed deeply into students' academic failure experience. Also, these theories were not used to analyze our data, consistent with phenomenography. The categories that we constructed for our results were strongly grounded with data from the interviews rather than from external theory. However, we recognize that our biases and personal experiences may have influenced the interpretation of the data and the identified patterns from which categories were constructed.

As a qualitative research method, phenomenography has received criticism about the nature of category construction: the final categories are constructed based on the relationship between the data and the professional judgment of the researchers (Bowden & Green, 2005). That is, the categories may reflect the bias of the researchers. In the present study, the main limitation was that I constructed categories as an individual researcher. However, Bowden and Green (2005) argued that individual researchers can make substantial contributions to the understanding of experiencing a phenomenon, but that a team of researchers might have taken that understanding further. Therefore, the categories constructed by an individual researcher may be less complete outcomes. Nevertheless, Bowden and Green (2005) also argued that many doctoral theses of high quality phenomenographic research have been accomplished by researchers working alone. Furthermore, they suggested that individual researchers can take deliberate steps to promote rigor and bracketing.

For the present study, I engaged in several steps to promote rigor and bracketing. First, I engaged with data analysis over a long period of time (about three years). Throughout this period of time, I took multiple breaks during analysis because of other academic demands. These breaks allowed me to return to the analysis with an open mind and to monitor and correct biased interpretations from previous analyses. Second, I searched for negative examples as well as supporting examples when constructing categories. For example, by constructing preliminary categories using the first 15 transcripts, I could use the remaining 11 transcripts to check for negative examples. Third, I had peer debriefings with another researcher throughout the multiple iteration process. During peer debriefing, I would describe the preliminary categories and this researcher would critique them. This researcher did not examine the data directly, and so the critiques were based on the evidence provided by me. These peer debriefings made me more aware and critical in refining categories during subsequent iterations. Using the feedback from peer debriefing, I could iterate on the construction of categories until a more complete and accurate description of categories emerged.

Although member checking is a typical step in a qualitative study, member checking is not necessary in developmental phenomenography because the goal is to categorize the range of experiences within a collective group rather than a series of individuals (Bowden & Green, 2005). For example, an individual transcript was not expected to align neatly with any one category, and no transcripts were interpreted in isolation to warrant member checking.

3.4 Results

3.4.1 Categories of description

During the interviews, students described a range of academic failures: a low exam score, a poor course grade, or an overall atrocious semester. When we analyzed the interview transcripts, we identified four categories of descriptions that captured the variety of students' experiences with academic failure; see Table 3.2. We named these categories with adjectives to describe students' overall response to a single failure experience. We further distinguished the categories using two dimensions of variation: students' attitude towards the specific academic failure and behavior in response to the failure. These categories are ordered by an increasing competence to address failure. By competence to address failure, we mean a combination of recognition of failure and ability to address failure effectively. For example, Unresponsive experiences describe students who do not even recognize a poor exam grade as a failure, whereas Avoidant experiences describe students who at least recognize their poor exam score as a failure.

We note that many of the more advanced students (third-year and above) described their experiences with academic failures that had occurred during their first two years in college. Therefore, these failure experiences may differ from how they experience academic failure at the time of the interview. Furthermore, students described different failure experiences based on different instances of academic failure. As a consequence, quotations from a single student may appear in multiple categories. When we report quotations, we use ellipses with square brackets, […], to indicate deletions of text.

3.4.1.1 Category 1: Unresponsive

The Unresponsive category characterizes experiences of students whose academic failure had no

Table 3.2: Categories of descriptions ordered by an increasing competence to address failure

	Categories of descriptions			
	1. Unresponsive	2. Avoidant	3. Floundering	4. Rebounding
Dimensions of variation				
Attitude towards specific academic failure experience	Oblivious	Discouraged and demoralized	Perseverant	Confronting
Behavioral response to specific academic failure experience	No change in behavior	Self-sabotaging behavior	Increased unproductive effort	Effective changes to succeed

impact on them: the failure resulted in no changes to their academic behavior. For example, after receiving a low exam score, these students did not feel compelled to change their academic behavior. These students appear oblivious to the failure. As a consequence, many of these experiences ended in larger academic failures, which were often poor end-of-semester course grades.

Ulysses described how he would not change his study habits unless the failure was big enough.

> What I did do was just kind of just continue on the same path, like, and sometimes if the failures aren't large enough, I'm just going to go down the same path and just come back to it. Unless it's big enough, […] it's not gonna direct me off my path of the same study habits. So, yeah, that's kind of rough. (Ulysses, 3rd year)

Quinn described a similar experience as Ulysses where she did not change her academic behavior and expected the problems to fix themselves.

> That's what happened freshman and sophomore year, is just not even getting thought to what went wrong and just kind of assuming that it'll fix itself. Like, "That was just

> a hard exam and I'll do better on the next- the next one won't be as hard." Um, but it's going to lead you down the same road if you don't change the habits that got you to that place in the first place.
>
> (Quinn, 3rd year)

The experiences of Ulysses and Quinn exemplify how students sometimes do not take the feedback from their poor exam grades seriously enough to change their academic behavior. As a consequence, their "same study habits" led to poor academic performance again in the future.

In addition to the experiences where students did not change after receiving a poor exam grade, there were experiences where students outright ignored their academic responsibilities. For example, Dan described his experience with enjoying the social aspect of college too much.

> Yeah, so my main failure, like I said, was that one semester, uh, in college. So, I was only taking like four classes, but I was partying too much. Kickin' it with my, you know, girlfriend at the time. Like, I was just so not in the school mindset. I was just trying to have fun. Then certain things just weren't going so well, so, should've controlled my drinking a little more. So yeah, then my grades definitely suffered because of that.
>
> (Dan, 4th year)

Dan was not taking his academics very seriously. He was clearly enjoying his social life—perhaps, a little too much. He was likely to have received low exam scores before the end of that semester, but he did not respond to these grades.

Similar to Dan, two non-traditional students, Felix and Yvonne, did not take their academics seriously.

> Focus. Uh, that’s been my problem all along, that's why I dropped out of college in the first place, and I had no focus. Having a goal in mind helps a lot too. Again, first time through college I had no goal, and it showed in my grades.
>
> (Felix, 2nd year)
>
> I ended up failing in my first year and ended up dropping out. And that’s why I said earlier that it’s really important to try and stay focused ’cause I got caught up in the whole, “I get to do whatever I want. I don’t have to listen to my parents. I can sleep all day if I want to.”
>
> (Yvonne, 4th year)

The lack of “focus” described by Felix and Yvonne indicate how they did not take academics seriously. As a consequence, they dropped out of college. Similar to Dan, both Felix and Yvonne were likely to have received low exam scores before they dropped out of college. However, they did not respond to these grades because they lacked “focus”.

Overall, we categorized these student experiences as Unresponsive because students did not respond to their academic failures. Students ignored the feedback from their poor academic performance and continued to do whatever they were doing previously. As a result, they jeopardized their future academic performance. Some students only had bad semesters, whereas other students dropped out of college entirely. In comparison with all other categories, the critical variations that distinguished the Unresponsive category were students’ oblivious attitude toward academic failure and their lack of any behavioral response. It is important to note that Felix and Yvonne, who had previously dropped out of college, had returned to an engineering program.

3.4.1.2 Category 2: Avoidant

The Avoidant category characterizes experiences of students whose academic failure had a negative emotional impact on them and who chose self-sabotaging changes to their academic behavior. For example, after performing poorly on an exam or a course, students lost interest in academics and engaged in behavior (e.g., skipping class or studying less) that hurt their chances of academic recovery. Students described their experience as "discouraging" and "demoralizing." The Avoidant category indicates an increase in competence to address failure over the Unresponsive category because these students recognize their academic failures. However, they still do not address their failures.

Owen described his failure experience as a vicious cycle.

> Um, I'm definitely discouraged by failure. Um, 'cause, like, even like short-term stuff, like, if I studied really hard for an exam, and I don't do as well on the exam as I thought I would, then I kind of, like, get discouraged that, like, my work didn't pay off. Um, and I feel like that's kind of like a vicious cycle. 'Cause then you studied less next time, and you do worse, and you study worse next time, and you do worse. Um, so definitely I think, definitely being on top of things counteracts that, but if you're not on top of things, then it kind of downward spirals.
>
> (Owen, 4th year)

Owen felt that his efforts were not being rewarded in the form of academic success, and he became less motivated to study on his next exam. Owen's failure experience led him to study less on subsequent exams as indicated by his remark, "you studied less next time […] you study worse next time." As a result, his academic performance spiraled downwards.

Similarly, Wayne felt demoralized after doing poorly on his first series of exams, despite the amount of effort he put in.

> The semester that I did really poorly in […] the first series of midterms [exams] didn't go so well and that made the second round much harder 'cause, you know, it was demoralizing and like despite like what I thought was, "Oh, I put in a lot of work and I did my best," to see the lack of results was very demoralizing […] I was working like 25 hours a week on research and that was a big distraction. So, when, you know, I started doing poorly than I would've liked to, I kind of would just focus on the research and the [research] work instead of my class work 'cause that [research] was going well, like, school was not going well so. The failures kind of frightened me off from confronting the problems that I had and prevented me from correcting, you know, what I was doing wrong that semester.
>
> (Wayne, 3rd year)

Wayne felt demoralized after his poor exam performance. Rather than confronting his problems, he used research as an escape as indicated by his remark, "I […] would just focus on the research," because his "[research] was going well", whereas "school was not going well." This escapism would only exacerbate his academic problems and decrease his chances of academic recovery.

When faced with academic failure, Adam and Cathy outright stopped going to classes.

> When I first started out college, […] after getting those Fs what do you do? Um, I was at that stage where I was looking for another major, I was sitting through the course catalog and like looking through all these majors and I'm like, "Oh, what fits

> me best than what I'm doing right now?" […] That stage is like "What do I do?" And the biggest thing was I would just, I would feel so bad about my mistakes I would just not do anything about it. I would not go to class, not do anything.
>
> (Adam, 4th year)
>
> One of the mistakes that I made was like, once I felt like I wasn't doing well in a class and I stopped going to lecture because I was like "Oh, I don't understand anything so why should I go anymore? I'm just wasting my time and I'm just gonna end up looking at my phone if I go there."
>
> (Cathy, 2nd year)

For Adam, after getting F grades on courses, he felt so bad that he did not want to do anything and ended up not going to class. For Cathy, once she felt that she was not doing well in a course, she rationalized that there was no reason to go to class. Both Adam and Cathy responded to their failures by not attending class or lecture, respectively.

Overall, we categorized these student experiences as Avoidant because students were essentially avoiding academics by skipping classes and by studying less on exams after their failure experience. Students' negative emotions from their failure resulted in behaviors where they studied less and avoided classes. Perhaps, if these students sought help from various resources on campus, they may have chosen more beneficial changes to their academic behavior. However, in the end, these students' self-sabotaging behavior led to poor academic performance in the future, similar to the Unresponsive category. In comparison with all other categories, the critical variations that distinguished the Avoidant category were students' discouraged attitude towards academic failure and their self-sabotaging behavioral response. Again, it is important to note that a majority of these experiences were described by more advanced students who were persisting in engineering. Although faculty and administrators might feel that students with Avoidant behaviors should be "weeded out," we caution against dismissing these students because, as exemplified by Owen and Adam, they can develop coping skills to persist to the advanced stages of their engineering programs.

3.4.1.3 Category 3: Floundering

The Floundering category characterizes the experiences of students who attempted to persevere by increasing their efforts toward their academics. For example, after receiving a low exam score, students "worked harder" or "put in more time" into their academics. In comparison with the Unresponsive and Avoidant categories, there was an increase in competence to address failure in that students recognized that failure could be addressed (e.g., by increasing their efforts). However, these efforts were unproductive in that they did not necessarily translate to success.

Max's experience described how working harder was not enough to address his failure.

> Sometimes you need other people to help you learn from your own failures. And there's that thing with, uh, getting, you know, getting caught in a circle […] Say you're trying to learn from your failure, and you think […] how you failed was just, "Oh, I didn't work hard enough." And then, you just try to work hard, and work hard and- then it never works.
>
> (Max, 5th year)

Max increased his efforts by trying to "work hard" to address his failure. Though he was aware of his failure and worked harder to address it, he failed to recognize that his increased efforts were not effective as indicated by his remark, “Sometimes you need other people to help you learn from your own failures.” Max’s inability to recognize that his increased efforts weren’t enough led to him “getting caught in a circle” of failure.

Xavier echoed Max’s experience in that he devoted the time and effort, but he was unsuccessful.

> I’ve been put on probation since winter break, and I’ve told myself I have to get like above an average of 2 [above a C] in my […] courses to get out of my probation at the moment. And I know that if I put in my time, everything, it just works out. Like, I see some class, I put in some time, and then I, like, do really well. But this term, I did put in the time. I really tried. But it didn’t really work out the way I wanted it. […] I’m like reflecting a lot on this term pretty much because of the way things have been going. I mean, I reflect on my mistakes. I fix it up. But put me in an exam, and suddenly, I’m down below the average. So, even though when I think I got it, I learned from everything, like everything from my homeworks, everything I did wrong, I fix it, but I go into an exam and suddenly everything is different.
> (Xavier, 2nd year)

When Xavier increased his efforts by devoting time in a previous course, he was successful. Based on that experience, he hoped that his increased efforts would help him this term as well. However, similar to Max, Xavier failed to recognize that devoting time, by itself, was not enough to address his failures this term.

Yvonne and Lucy described their experience with low scores on their first exams.

> At first [after failure], I’m like, “Oh my god. I didn’t do it. I didn’t do it.” And then, I’m like, “Well, maybe I could do this or I could this.” And then, I don’t know, all

> these ideas just start coming to me on how I could re-work this situation and either make it work in my favor or how to do it differently. So, usually I just keep my ideas in my head or I write them and then try and figure out what path to take next. […] My first physics exam here, I scored a 35, and I'm pretty sure I cried for like three days. [Laughs] Um, but after that, you, I don't know, kind of get used to realizing that a lot of the hard classes– the exam scores are low. So, the best thing is, one, don't get discouraged by low exam grades 'cause chances are if you did bad, everyone else did. Um, and just cross your fingers and hope you beat the [grading] curve. [Laughs] That's what I do.
>
> (Yvonne, 4th year)
>
> I got a 37% on the first [exam]. Went and talked to the professor, and he said pretty much, "I don't know what to tell you. It looks like you don't know anything." [Laughs] And I was like, "Okay. I'm going to do all my homework and office hours, so I can ask – get my questions answered. I'm going to study with a friend for the exam." I found a really neat website that has instructional videos on how to solve all the class problems that were on the exam. Got a 40 something– 45% on the final. And that sounds terrible because, you know, two very, very low grades. With my relatively decent homework scores and a really, really generous curve, I ended up with like a C- in the class? So, I was– it worked out. That's not failure, that is scraping by. And praying for a good [grading] curve.
>
> (Lucy, 4th year)

In response to their failures, Yvonne and Lucy thought of and implemented strategies to address their failure (i.e., increased their efforts) instead of analyzing the reasons for their failure. They also did not know whether their efforts would succeed, as indicated by their hope for a “curve.” We interpreted their behavior as increased unproductive efforts because they were focused on efforts that may not have been effective.

Overall, we categorized these student experiences as Floundering because students’ increased efforts were not effective at addressing their failure. In comparison with the Unresponsive or Avoidant categories, students recognized that they could address their failures by increasing their academic efforts. However, they could not gauge the effectiveness of their efforts. Their inability to gauge the effectiveness of their increased efforts suggested that they did not fully recognize their academic shortcomings. As a result, these students persevered using unproductive strategies that did not necessarily lead to success. In comparison with all other categories, the critical variations that distinguished the Floundering category were students’ perseverant attitude towards academic failure and their increased unproductive efforts.

3.4.1.4 Category 4: Rebounding

The Rebounding category characterizes the experience of students who confronted their academic failure and resolved to change their behaviors to succeed in the future. For example, after doing poorly on an exam or a course, students analyzed what they did wrong and made the necessary changes to not repeat the same mistakes. Some students described their experience as a “wake-up call.” Some also developed a strong desire to prove themselves. In contrast to the Floundering category, the Rebounding category described an increase in understanding failure in that students identified and implemented effective changes that led to future academic success.

Evan’s experience summarizes this category well. He had reduced his study habits compared to his previous semesters, and this behavior had resulted in poor grades.

Evan: I would consider last semester a failure. So, I mean that, that was sort of a wake-up call. And then from that, I started to think what I did wrong – what are the things that I did wrong last year, and what to change those, no? […] When my final grades came in over break […] I had that minute of panic […] When I had some time to myself, I began to think, “Okay,” because in the previous semesters I haven’t done that badly, no? So, then I start to think, “Okay, what was different in this semester and the previous [successful] ones? What are things that I stopped doing and what are things that I started doing?” […] The first two semesters I used to do absolutely everything that they, that professors assigned, and all the extra credit problems, non-graded homework, I did absolutely everything, eh? And then I did well, no? I came back for another semester, I started working like I normally did, then the first round of midterms [exams] came. I did very well, then after that it's like, oh this is easy, no? I don’t need to put in much effort! So I just stopped doing all the work I used to do. I started doing the bare minimum, and then pbbbt [blowing raspberries], down. […]

Interviewer: And so, basically you went back to doing everything?

Evan: Right now, yes. Of course, it is hard after a semester of doing the minimum to start doing the most possible. That's a difficult transition

(Evan, 2nd year)

Upon comparing his immediately preceding semester with other successful ones, Evan confronted himself, as indicated by his remark, “I just stopped doing all the work I used to do. I started doing the bare minimum.” To address his failure, Evan returned to doing what helped him succeed in previous semesters: “I did absolutely everything […] that professors assigned” and more.

Similar to Evan, Ben shared details of the specific changes he made after earning D grades in multiple courses.

> Looking back at my freshman and sophomore year, I had multiple classes with D's. And, um, I looked back at it and was like, "What was I doing?" And I was like, "I was going out a lot and spending a lot of time on Facebook instead of doing homework." So, I got rid of both of those. I didn't go out drinking and I didn't do Facebook. I got rid of my Facebook and I still don't have it. And since then, my grades have been a lot better, hah […] No matter what, if you get it or not, you have to look at what didn't you do to get to where you are now, and how can you make it better. So, it's kind of like the engineering perspective of "Oh, this trial didn't work, so what are we gonna change to make it work again, or make it work better?" or "I have this now" or "How can I make it even better?"
>
> (Ben, 4th year)

When reflecting on why he was earning D grades, Ben identified "going out a lot and spending a lot of time of Facebook" as two reasons why he was not spending enough time "doing homework." He confronted these problems and made changes, as indicated by his remark, "So, I got rid of both of those." These changes were effective, as indicated by his remark, "And since then, my grades have been a lot better." Similar to Evan, Ben was able to identify the causes that negatively impacted his academics and made lifestyle changes to effectively address them.

In another account, Greg included less specifics but described how his failure experience pushed him to be a better student.

> I failed the first test when there was only three tests within the entire class [course]. And there is no way for me to fix it and like be able to make it through. The only way

> out would be to retake the course. Um, which I did. And I, going in to the semester, um, I looked on myself and I made sure that I was ready to change things around for this course, and be prepared for everything coming at it because I knew what to expect with the difficulty […] Because after I failed that [first] test, I realized that was the point– I went through this like, moment of disparity [*sic*] where it's like, "I might not be able to make it through this program, I might have to find another career path to make it, um, in the job market." Um, within that disparity [*sic*], it was really rough. I realized that I wasn't um, as intelligent as other people. Um, I realized that things didn't come as easy to me as other people. And from that disparity [*sic*] I realized that I can, I know I can do better. Like there is a feeling that I might have done bad on this test, but I know I can do better. There is a feeling like I want to prove myself that I can do this. And so, when I turned that around, I came– I did turn it around, and it made me know that I was able to do this from the beginning.
>
> (Greg, 2nd year)

Greg confronted his failure, as indicated by his remark, "I looked on myself and I made sure that I was ready to change things around for this course." We do not know the details of what he changed, but he made changes that were effective, as indicated by his remark, "I did turn it around." We interpreted his whole response (confrontation with failure, analysis of his intelligence, resolve to change, and the successful outcome) to fit the Rebounding category.

Pam, an international student, described her difficulty during her first semester in college in a new educational system.

> For math, I was hugely disappointed because that was my second time taking the class [course] – I took it in high school. But then, the process, the method of thinking,

> the test-taking strategy, the learning process, and showing that you have learned process were completely different. So, I was disappointed. I felt that I could've done better. Um, it was – it felt bad. But then, it just meant if I'm going to take it again, I have to prove the world and myself that, you know, that was a horrible semester, that this does not define me. […] This is like the only time I can think of failure. Like, this last semester […] I tried to find out how I failed, what I failed, every single thing I did and why – what I was – everything I did in the course of the period that led to the failure. How it – whether it led to the failure or it was one of the things that made the failure not as bad […] So, improve on these [failures], counter these [failures], and general things that others did to make themselves better.
>
> (Pam, 1st year)

Similar to Greg, there were no specific details of change in Pam's account. However, Pam clearly accepted that she had failed, and she confronted her failure by examining "everything I did in the course […] that led to the failure." Unlike Greg, we did not know the outcome of her confrontation with failure, but we interpreted her attitude towards addressing the causes of her failure to fit the Rebounding category.

Overall, we categorized these student experiences as Rebounding because students recovered from their failures by confronting their failures and making changes to ensure success in the future. Students could pinpoint what they needed to change and resolved that they needed to make these changes if they wanted to succeed. The Rebounding category was distinctly different from the Floundering category because there was an increase in competence to address failure in that they made effective changes towards success. In comparison with all other categories, the critical variations that distinguished the Rebounding category were students' confronting attitude towards their academic failure and their effective changes to succeed.

3.4.2 Students with multiple failure experiences

Several students had multiple failure experiences. These multiple experiences indicated that students did not experience academic failure the same way for every one of their failures. In this section, we show examples of these multiple failure experiences.

Adam had an Unresponsive experience with a low exam score and an Avoidant experience with a failed course.

> So, evaluating failure is understanding what are the consequences of it. Um, if I were to get a bad [exam] grade as a freshman, initially that, for me it's like I didn't understand what it meant. I was like, "Oh, bad grade. Okay, I'll do better next time," but I didn't know how to do better, because, for one, I was not accepting this failure. I was just saying, "Oh, it's normal. College is hard." […] After getting those Fs [as course grades] what do you do? Um, I was at that stage where I was looking for another major, I was sitting through the course catalog and like looking through all these majors and I'm like, "Oh, what fits me best than what I'm doing right now?" […] That stage is like "What do I do?" And the biggest thing was I would just, I would feel so bad about my mistakes I would just not do anything about it. I would not go to class, not do anything. […] So, what happened to me […] after seeing those grades, I would look at those grades, I would look at my school, and just be completely disinterested in it. Like I, I just want to do this instead of that, I should

just pick an easier major and blow off college.

(Adam, 4th year)

Adam had an Unresponsive experience after receiving low exam scores, because he had rationalized his failure as “normal.” His unresponsiveness led to poor semester grades. After receiving F course grades, Adam became “disinterested” in school and even skipped class. We categorized this latter experience as Avoidant because of his self-sabotaging behavior.

Cathy had an Avoidant experience when performing poorly in one course and a Floundering experience when she was retaking Calculus III.

> One of the mistakes that I made was like, once I felt like I wasn’t doing well in a class and I stopped going to lecture because I was like, “Oh, I don’t understand anything so why should I go anymore? I’m just wasting my time and I’m just gonna end up looking at my phone if I go there.” […] The class that I failed in last semester was [Calculus III]. And I’m taking it again this semester. And we're reaching that same point that […] I lost my touch with that class, and I still, I still can’t get over that point, I, I don’t understand it, I’ve been going to every lecture, I just don’t get it. […] I think, “Why can’t you do this? Why are you stupid? I don’t understand why you can’t do this!” Then, I try to read from the books and the book - the book is always so wordy! I don’t understand, it’s a math class, hah! So, I try to read from the book, but the book always has complicated notations, complicated words, and uh, so I can’t understand it on my own. I think about going to office hours but I’m afraid of going to office hours and looking stupid. Also, when you go to TA office hours, uh, they tend to like, ask you questions in order to get you to the answer. They don’t give you the answer right away. So, I’m afraid of going there and them asking me questions

> and then in turn looking stupid because I don't know the answers to the questions. (Cathy, 2nd year)

Cathy had an Avoidant experience when she stopped going to lecture after she felt like she wasn't doing well in that course. During the next semester, Cathy retook her calculus course, and she increased her academic efforts to succeed as indicated by her remarks, "I've been going to every lecture" and "I try to read from the books". However, it is clear that she too focused on self-blame to effectively address her failure. We categorized this experience with retaking calculus as a Floundering experience because Cathy was struggling with unproductive efforts.

Quinn had both Floundering and Rebounding experiences through one course.

> I mean there's been classes in, you know, past semesters, like last semester, that I've gotten like a D and a D on the midterms [exams], and then, just like got it together before the final exam: gone in for help, done all the homework, worked with my friends […] It was like the whole– every midterm was like terrible. I have no idea what was going on. I had no idea how to even study. And then, finally, in like the last month of the semester I just pulled out all the stops and I ended up being very successful in the course. So, yeah, that was one of my biggest turn arounds. (Quinn, 3rd year)

Quinn recognized that these exams grades were "terrible" (i.e., recognizing failure). We do not know what efforts that Quinn made in response to her first exam, but based a subsequent D exam grade, we have evidence that her efforts didn't work (i.e., unproductive efforts). Combining our interpretations of Quinn's recognition of failure and unproductive efforts, we interpreted the first part of her course experience as Floundering. However, we see that she "pulled out all the stops" (i.e., confronted her poor performance) and "ended up being very successful in the course" (i.e., efforts were effective). Again, we do not know the specific strategies Quinn used, but we categorized her confrontation with her poor performance and effective efforts as a Rebounding experience. Quinn's experience illustrates that students can succeed even after low first and second exam scores. Furthermore, this Quinn was the same Quinn whose other failure experiences were also used to provide evidence for the Unresponsive category.

Ulysses described a general failure response that fit under the Unresponsive experience and a Floundering experience in a different instance.

> What I did do was just kind of just continue on the same path, like, and sometimes if the failures aren't large enough, I'm just going to go down the same path and just come back to it. Unless it's big enough, […] it's not gonna direct me off my path of the same study habits. So, yeah, that's kind of rough. […] When I got a D in physics […], there was a disconnection, because I thought I did well on the final. I was like "Okay, I studied a decent amount for the final. Like I think I did better than the midterm [exam]. You know, I expect, you know a decent grade," and I was like "Ah". Like I don't react negatively if I expect, "Alright, I got a D in the class. I know what I got." But when the results don't line up with my perceptions, it's like, "Oh, why is that? I'm a little confused."
>
> (Ulysses, 3rd year)

In the beginning of the quotation, Ulysses said that after small failures, he would not change his study habits. We categorized this experience as Unresponsive because he would not change his academic behavior after failure. Later, when describing his experience with a course, he performed poorly on his final exam even though he "studied a decent amount" (i.e., increased unproductive efforts). We categorized this experience with a course as Floundering because his increased efforts were unproductive. Ulysses's experience illustrated how students get "confused" when their performance does not match their effort. It is likely that students like Ulysses do not know how to study effectively.

Simon described an Avoidant experience during his first semester and a Rebounding experience during his next semester with the help of the counseling center.

> Well last semester I got very very down. I was very very unhappy. Very… I took hit to the morale pretty strongly, yeah. Depressed? I might use that term. I'll probably use that term… It was the first semester here. It was very discouraging. Because [college is] a whole new ball game. Ain't used to it and you start doing bad, you ain't used to doing bad, and, you know, no matter how smart somebody is, you know, everybody has a point where, you know, they get discouraged. […] This semester I did better about that. Yeah, you're gonna get bummed out a little bit after a bad exam, but I didn't stay bummed out. I was able to look over the exam and see what I did wrong. Last semester after the second round of exams, after my second—yeah my second chem exam, I got down, like it was done, I shut—I was done for the rest of the semester. I was out. […] I went to the counseling center [this semester] and we discussed things[, which resulted in helping me become] more self-aware. I'd look at [my last semester] and say "Okay, I did do bad, but that's because I didn't do anything last semester." I didn't study, I didn't—I wasted all my time. I got down and wasted more time. I mean that's a cyclical thing, that's not going to help you out at all. Like by knowing why you failed you may not immediately improve all the things about it. You can at least recognize that you're not stupid, but you did mess up, and so, [knowing why you failed will] help you take steps. Like understanding it has

helped me take steps to where I want to be in terms of my work ethic and my study habits. Am I there yet? No. I'll tell you right now I'm not. As a matter of fact, today's- I still got a lot more studying to do for two exams I got tomorrow. Those are going to be rough. Aghhhh that's going to be rough. But that's on me. I do know considerably more in those courses and I mean that I know that- I know that I'm not stupid because I've done better this semester in those courses. I'm retaking these two classes for grade replacement: [calculus and chemistry]. Right now, I'm getting a B in it. So even though I can definitely- I can spend time right now beating myself up for not studying more up to this point or I can say "Okay, I was stupid, but you can still learn a little bit more. You can do the best you can and give them what you did to yourself on the test and you recognize that you- when you study, you get it. When you don't, you don't."

(Simon, 1st year)

We can see how Simon started with an Avoidant experience because he was "done for the rest for the semester." We interpreted his statement of "I got down" and "I wasted all my time" as indication that he was less engaged in his academics, because he was discouraged. After receiving help from the counseling center, he became more self-aware about his behaviors, and we interpreted his statement of "knowing why I failed" as an increase in recognition of failure. To address his failures, Simon resolved to take steps to improve his work ethic and study habits (i.e., confronting his failures). We categorized this latter experience as a Rebounding experience because Simon was confronting his failures and making effective changes to confront them. The effectiveness of his changes can be seen in how Simon was performing better in the two classes he was retaking (i.e., "I'm retaking these two classes… Right now, I'm getting a B in it"). Simon's experience illustrates how students can succeed with the help of campus resources.

3.4.3 Limitations

One limitation of our findings was that our categories were not constructed based on a specific type of academic failure. For example, we did not substantially differentiate between low exam scores, poor course grades, and atrocious semesters. The consequences for each of these failures are significantly different. For example, exam scores can be improved upon, whereas course grades are more or less fixed. In addition, students' GPAs are less impacted by a single poor course grade than by multiple poor course grades. Therefore, in interpreting our results, the Unresponsive category may be more relevant to students' experiences with low exam scores than their experiences with poor course grades and atrocious semesters.

A second limitation of our findings was that our categories were not constructed to account for several important factors that impact persistence. For example, we did not construct our categories based on personal or non-academic problems such as financial instability, mental health issues, family emergencies, or medical emergencies. In addition, our data did not have sufficient evidence to construct categories based on students' usage (or non-usage) of academic support services (e.g., advising, counseling, and tutoring services). As part of our bracketing process, details of these problems were removed during data analysis because most students did not explicitly connect these problems to their failure experience.

A third limitation of our findings was that categories were constructed after including the outcomes of students' responses to their failure experience (e.g., students do not succeed even after putting in more time and effort after a low exam score). The categories could be criticized for the inclusion of outcomes because students cannot control the outcome of their responses to failure. For example, the critique for the Floundering category is that, currently, it only captures the experience when students fail even though they exert more effort, even though sometimes more effort may be sufficient to succeed. When additional effort suffices, the experience may fit the Rebounding category. We argue that this critique actually supports the hierarchical structure of our categories: students' increasing competency to address failure. That is, the Floundering category captures the experience of students who have not yet identified what efforts will sufficiently address their failures, including students who may believe that more effort is sufficient based on previous successes (i.e., Xavier in *3.4.1.3 Category 3: Floundering*). If outcomes were not included, our categories would have been constructed differently. We also note that the main epistemological assumption of phenomenography emphasizes the logical relationships between different ways of experiencing a phenomenon. That is, the categories focus holistically on the collective human experience, even though the phenomenon may be perceived differently by different people under different circumstances (Bowden & Green, 2005).

A fourth limitation of our findings was that the time when students experienced failure was not consistent. For example, not all failures were during students' first or second year. When students experience academic failure early in their engineering programs, they may question their ability to succeed in engineering, whereas when students experience failure later, they may not share the same concern. However, because our selection criteria recruited students who had failed a required technical course as opposed to technical electives, our participants were more likely to share failure experiences from the early stages of their engineering program.

A fifth limitation of our findings was that they were limited to one institution. As a consequence, these findings may not extend to engineering student populations at other institutions. However, we note that the goal of phenomenography was not to generalize findings across the population. The findings should be viewed as what the authors observed within the sample, and other categories may have been constructed if the sample were different. However, our sample was diverse, and the sample size of 26 was within the range of 20 and 30 interviews for a phenomenographic study (Bowden & Green, 2005).

3.5 Discussion

Using phenomenography, we answered the research question, “In what variety of ways do persisting engineering students experience academic failures?” We developed four categories to describe the experience of students who received low exam scores and poor course grades and had awful semesters. We hierarchically ordered these categories based on an increase in competence to address failure. The Unresponsive category describes the experiences of students who appear oblivious to failure and do not change their academic behaviors. These students included those who did not view low exam scores as a failure and those who failed because they were not focused on their academics. Next, the Avoidant category describes the experiences of students who become discouraged by their failure and exhibit self-sabotaging academic behaviors. When compared with the Unresponsive category, the Avoidant category includes students who recognize their failure but feel too discouraged to address their failure. Next, the Floundering category describes the experiences of students who persist through failure and increase unproductive efforts towards their academics. When compared with the Avoidant category, the Floundering category includes students who recognize that they can address their failures through increased effort. However, these increased efforts do not lead to success because these efforts are unproductive: students “work harder” but may not “work smarter.” That is, students fail to identify why their efforts are unproductive. Last, the Rebounding category describes the experiences of students who confront their failures and make effective changes to their academic behavior. When compared with the Floundering category, the Rebounding category portrays students who effectively address their academic failures. Furthermore, we found that students had different experiences for different instances of academic failures. For example, Simon described an Avoidant experience during his first semester but a Rebounding experience after reflecting on that semester with the help of the counseling center.

3.5.1 Our findings refine our understanding of engineering persisters who encounter difficulty

We compare our findings with Suresh's study on persisting engineering students (2006). Suresh (2006) found that important factors for persistence were students' determination and decisions to persist when encountering difficulty. Consistent with these findings, we found that the Floundering and Rebounding categories described the experience of students who persisted through academic difficulties. In contrast, we also found that Avoidant experiences described students who did not exhibit qualities of persistence when encountering difficulties. Though they persisted in the engineering program, these students exhibited self-sabotaging behaviors such as skipping classes or studying less, because they were too discouraged by failure. Our findings refine the qualitative findings by Suresh (2006) in that not all persisting students exhibit determination to not quit when they encounter difficulties.

Furthermore, though Suresh (2006) also found that support from family, faculty, or administrators were important for student persistence, we did not include the variety of social supports in our categories of descriptions, because students had varying experiences with social support, and because we did not ask deeper questions on support-related questions in our semi-structured interviews. We were more interested in students' attitudes and behaviors towards failure. However, students did mention social support (or lack thereof) in their interviews. For example, students described supportive and unsupportive family members, supportive and unsupportive academic advisors, and helpful and unhelpful faculty. In future work, we will consider the impact of social support on students' experience with academic failure.

3.5.2 Our findings extend our understanding of shame-resilience and shame-nonresilience to engineering students

We compare our findings with the study on students' response to shame (Turner et al. 2002). Turner et al. (2002) described the behavior of shame-resilient students as having "the tendency to bounce back after a shame reaction with increased motivated behavior that included and resulted in relatively higher levels of academic achievement" (p. 84). Furthermore, these students perceived that their first exam grade was unacceptable and felt a need to perform better. If we were to interpret how students "perceived that their first exam grade was unacceptable" and how they "felt a need to perform better" as indicators of attitudes towards "confronting failure" and "increased motivated behavior that included and resulted in relatively higher levels of academic achievement" as "effective changes to succeed," then these shame-resilient students fit the Rebounding category.

In contrast to shame-resilient students, Turner et al. (2002) described shame-nonresilient students as ambivalent, confused, and conflicted. Shame-nonresilient students continued to use the same unsuccessful strategies they had used for the first exam. Some students resigned to studying less because they were unmotivated to study even though they knew they should. The behavior of students who tended to "use the same unsuccessful strategies they had used for the first exam" fits the Unresponsive category where students did not change their behaviors after their failure experience; see Ulysses and Quinn in *3.4.1.1 Category 1: Unresponsive*. However, the Unresponsive category described students who did not recognize failure. By not recognizing failure, these Unresponsive students may not have experienced shame. Turner et al. (2002) were not clear whether all shame-nonreslient students felt shame starting from the first exam or from the whole course experience. Regardless, if these students had increased their efforts by devoting more time but still using the same unsuccessful strategies, we would categorize their experiences as Floundering. In contrast, the behavior of students who "resigned to studying less because they were unmotivated to study" (by their low first exam score) fit the Avoidant category where students adopted self-sabotaging academic behaviors because they were discouraged by their failure; see Owen and Wayne in *3.4.1.2 Category 2: Avoidant*. Turner et al. (2002) suggested that self-regulatory processes separated shame-resilient and shame-nonresilient students.

Additionally, Turner et al. (2002) described one student who transitioned from shame-nonresilient to shame-resilient. Their finding is consistent with our findings in that we described Quinn as an example of someone who had both the Floundering and Rebounding experience in one course; see Quinn in *3.4.2 Students with multiple failure experiences*.

Our findings refine our understanding of the experience of shame-nonresilient students because they may fit two of our categories (Unresponsive and Avoidant) and possibly a third (Floundering). Also, the Rebounding category is consistent with the experience of shame-resilient students. Furthermore, regarding students with multiple failure experiences, our categorizations of Quinn's experiences are consistent with the student who transitioned from shame-nonresilient to shame-resilient; see *3.4.2 Students with multiple failure experiences*. Last, our finding extends the shame-resilient or shame-nonresilient response of advanced psychology students to engineering students.

3.5.3 Categorizing the experiences of departers from Meyer and Marx (2014)

Meyer and Marx (2014) described the experiences of four engineering departers: Bob, Jenny, Zach, and Karl. If we were to categorize the experiences of these departers using our categories of descriptions, we would categorize the overall experiences of Bob, Zach and Karl as Floundering, because they persevered through failures, and because their increased efforts were unproductive. More specifically, Bob and Karl were forced to leave their engineering program due to their institution's policy that prohibited degree progression after three failed courses. Zach chose to leave because he reasoned that his grades were only average and that they would only worsen as courses became more demanding. We did not categorize the experience of Jenny, because she did not fail any courses. Her decision to leave engineering was primarily influenced by the time pressures of her new job and the course demands of her engineering program. Furthermore, she wanted to maintain her 4.0 GPA. She eventually switched into the communications program, where she maintained her 4.0 GPA. In fact, the other three departers were also very successful in their new majors.

Excluding Jenny, the other three departers all had Floundering experiences in their engineering journeys. These journeys described their experience over multiple years, providing a sense of how long these students endured Floundering experiences. When we combine our findings with the findings by Meyer and Marx (2014), we can infer that students who have Floundering experiences over a long time are at risk of departing from engineering programs. Interventions that support students with Floundering experiences may help retain these students.

3.5.4 Connecting our results with the theories that informed our interview protocol

In the following sub-subsections, we connect our results with the theories that we used to inform our interview protocol. Afterwards, we describe implications in the next subsections

3.5.4.1 Mindset theory

Students with the growth mindset believe that intelligence can improve with effort, whereas students with the fixed mindset believe that intelligence cannot be changed (Dweck, 2006). Our study did not focus on students' mindsets specifically, but we found evidence of the growth and fixed mindset in our interviews with Lucy and Cathy, respectively.

Lucy explicitly mentioned in her interview that she knew about mindset theory.

> **Lucy**: I know that there's fixed mindset and growth mindset. Fixed mindset is "I am good at math." And then you only do math because that's what you're good at. Growth mindset is "I can be good at math if I try hard, or if I learn." And it involves keeping the thought that you can change? Or keep the concept I guess, in mind. And that's- you're always changing and developing as a person? I guess?
>
> **Interviewer**: Well, do you believe in it [the growth mindset]?
>
> **Lucy**: Yes. I do. Quite a bit.
>
> (Lucy)

Previously, in our results, we categorized Lucy's failure experience with a course in the Floundering category. She put up an increased effort in response to her failure. Perhaps it was the growth mindset that helped her persist despite her failures within that course.

In contrast, Cathy described her unhelpful habit of blaming herself for her shortcomings.

> When I don’t meet certain goals – so, this is actually one of the bad habits that I have. Um, I blame myself a lot for them, and I just, I keep– it’s, it’s not very, it’s not a very self-compassionate habit. I just, uh, keep telling myself, “Oh, you’re terrible at this. You must be really stupid.” And uh, anything else that I try to provide myself evidence of the contrary, like I say, “Oh, but I’m doing well in that other class!” My mind just goes like, “No, that must be a fluke. In actuality, you're actually stupid. You’ve got terrible grades in this other class.”
>
> (Cathy)

Cathy voiced her fixed mindset when she blamed herself for being “terrible at this” and “stupid.” Previously, in our results, we categorized Cathy’s multiple failure experiences under both Avoidant and Floundering categories. In those experiences, we saw evidence of her fixed mindset as she consistently blamed herself for being “stupid.” Perhaps, it would benefit Cathy to adopt a growth mindset so that she could focus on how to improve rather than blaming herself.

Beyond these two examples, there were no clear examples of the mindsets in students’ failure experiences. Therefore, we caution against interpretations that stereotype students in a certain category as having a certain mindset. However, we would not be surprised to see examples of the fixed mindset in students who have Avoidant experiences, like Cathy, or the growth mindset in students who have Floundering experiences, like Lucy. Furthermore, when considering our findings where students have multiple failure experiences, there is potential to influence students’ interpretation of failure before their next failure, for example, through interventions that promote the growth mindset.

3.5.4.2 Goal orientation theory

According to Dweck (1986), students with the growth mindset tend to adopt mastery goal orientations, whereas students with the fixed mindset tend to adopt performance goal orientations. We primarily used the synthesis by Kaplan and Maehr (2007) on the contributions and prospects of goal orientation theory. The mastery goal orientation describes an individual's purpose for *developing* competence, for example, focus on learning, understanding, and developing skills. In contrast, performance goal orientation describes an individual's purpose for *demonstrating* competence, for example, creating an impression of high ability and avoiding an impression of low ability. Performance goal orientations can be divided into performance-*approach* goal orientations and performance-*avoidance* goal orientations (Elliot, 1999). The performance-approach goal orientation describes an individual's focus on the possibility of achieving success, whereas the performance-avoid goal orientation describes an individual's focus on the possibility of failure, and on the attempt to avoid situations in which they will receive evaluations. The mastery goal orientation has been associated with positive outcomes such as effort, persistence, self-efficacy, and self-regulated learning. The performance-approach goal orientation has been associated with positive outcomes such as persistence, positive affect, and grades. The performance-avoid orientation has been associated with negative outcomes such as low efficacy, anxiety, avoidance of help-seeking, self-handicapping strategies, and low grades (Kaplan & Maehr, 2007).

We can see how the persistence described by the Floundering and Rebounding categories is related to the persistence associated with mastery and performance-approach goal orientations. However, our categories were not constructed with evidence using goal orientation theory. Consequently, we do not know how the categories and goal orientations are related. The self-sabotaging behavior described by the Avoidant category resembles the self-handicapping strategies from performance-avoid orientation. For example, Owen "studied really hard for an exam" but got discouraged when his "work didn't pay off." As a result, he fell into a "downward spiral" where he "[studied] less next time" and performed "worse." Similarly, Wayne "put in a lot of work" but saw a "lack of results," which was "very demoralizing." He then used research as a "big distraction" (i.e., spending less time on "class work") because "[research] was going well" and "school was not going well." Cathy also described how she was "afraid" of going to office hours and having the teaching assistant asking her questions, because she did not want to look "stupid" because she wouldn't know the answers to the questions.

Though goal orientation theory helps us understand the behaviors of the Avoidant, Floundering, and Rebounding categories, it is unclear how the theory relates to the Unresponsive category. Perhaps, the experiences in the Unresponsive category could be compared to not having either a mastery or performance goal orientation. For example, in the Unresponsive category, Felix and Yvonne described how they both lacked "focus," which led them to dropping out of college. Also, Dan described his experience where he was not in the "school mindset" (i.e., no academic goal) because he was "just trying to have fun." However, the lack of goal orientation does not explain the lack of academic behavior change where students may use the same unsuccessful strategies that led them to the failure in the first place. Overall, students' motivations and reasons for their behavior might vary and need further research.

3.5.4.3 Theory of grit

Grit is defined as "perseverance and passion for long-term goals" and "entails working strenuously toward challenges, maintaining effort and interest over years despite failure, adversity, and plateaus in progress" (Duckworth et al., 2007, pp. 1087–1088). Grit was actually our original motivation for the study: we wanted to better understand gritty students in engineering. Grit is related to our study in that we interpret "long-term goals" as degree attainment and "maintaining effort and interest […] despite failure" as persisting after academic failures. Though all the students that we interviewed were persisting in engineering after their failure experience, the Floundering and Rebounding categories described the attitudes and behaviors that most resembled grit.

In particular, Quinn's multiple failure experience in a course (categorized under both Floundering and Rebounding) described gritty behavior. She had earned a "D and a D on the midterms" (i.e., consecutive poor exam grades) and then "pulled out all the stops" (i.e. persisted with more effort) to end up "being very successful in the course." Quinn was not discouraged by the multiple poor exam grades and continued to persist by putting in effort.

In contrast, we observed non-gritty behavior in the Avoidant category. In the Avoidant category, Owen and Wayne were too discouraged by their poor first exam grades that they chose to study less or focus on research, respectively. Furthermore, Adam and Cathy stopped going to class because of their failure experiences. These Avoidant behaviors described students who did not "maintain effort […] despite failure".

However, we also observed "gritty" behavior in Dan's interview. We note that this experience was not in response to failure; rather, it exemplified gritty behavior that led to failure. This caveat is important because this behavior resembled the increased efforts of the Floundering category that were not effective.

> Sometimes, like exams just, they just don't happen the way you want them. But like, an example, me and my friend, we did like a hundred practice

> problems in the book, and we still didn’t do well on the first exam. That really pissed me off. I’m just like, “You [the professor] said, ‘Practice the problems in the book.’” And we still didn’t do well.
>
> (Dan)

Dan’s behavior suggests that gritty behavior can lead to unproductive perseverance, where success is not commensurate with effort. Our Floundering category refines the theory of grit for academics in that, for some students, “maintaining effort… despite failure” to achieve “long-terms goals” can lead to increased unproductive efforts, some of which can result in departing engineering programs. The negative outcome of grit is further evidenced in the experiences of Bob, Zach, and Karl in the study by Meyer and Marx (2014), who departed from engineering after enduring Floundering experiences over a few years.

Gritty behavior is a desirable trait for engineering persistence. However, gritty behavior alone does not help students succeed. This claim is supported by the unproductive efforts evidenced in the Floundering category. Students need to not only “work harder” but “work smarter” by identifying what efforts are ineffective.

3.5.5 Implications for course and program policies in engineering

In engineering design, failure is a central theme (Petroski, 1982, Petroski, 2006): the engineering design process is an iterative process that involves learning from failure and testing to failure. Failure is normal, even anticipated, when a new product is being developed. By this logic, failure is not a mistake but an essential feedback mechanism for improvement. However, academic failure is rarely treated the same way.

In academics, failure is something that is undesirable or to be avoided. Failure is criticized, whereas success is praised. From life experience, students may associate academic failure with negative experiences such as punishment (by parents) or shaming (by peers or the self). By this logic, failure is devalued, shameful, and to be hidden or erased.

As engineers, we practice what we do *not* teach in that we do not avoid failures. Therefore, we should instead teach what we practice. We can still assign poor grades to poor performances, but we should give ample chances for redemption. For example, to help students learn from failure, we can adopt a second-chance testing policy. This policy allows students to take a second-chance exam on the same content. If the student earns a higher score than on the original exam, the second-chance exam score replaces the original exam score. Second-chance testing is important in engineering courses, because cumulative exams are common in engineering. That is, cumulative exams are common because new course content often builds on old content. Therefore, it is important to master old content before learning new content. However, traditionally, without second-chance testing, when students perform poorly on their first exam, they need to relearn old content while learning new content but end up taking a second exam without knowing if they have mastered the old content. This traditional exam structure sets up struggling students for failure rather than redemption.

Some instructors may consider second-chance testing to be too time consuming because of logistical issues like additional grading, exam scheduling, and creating another exam. As an alternative, we suggest frequent formative assessments in class that test students' understanding of course content without the logistical constraints of an exam. Another easy alternative is to allow a student's final exam score to replace the lowest score on one previous exam if the result would improve the student's course grade.

For engineering program policies, we can implement grade replacement policies where students can get full grade replacement if they perform better when retaking failed courses. Failing an introductory course impacts students' persistence and lengthens students' time to degree (Felder, Forrest, Baker-Ward, Dietz, & Mohr, 1993). For institutions where prerequisites are strictly enforced, failing a course can extend time to graduation by a semester or a year. We explained previously in the Methods section that students who fail Calculus I, which is required for Physics I, which in turn is required for Statics, could extend their time to graduation by at least one semester. In addition, failing a prerequisite course limits students' opportunity to take advanced courses in a timely manner. Furthermore, there are financial costs associated with delaying graduation as student will need to pay tuition for additional semesters when they could have been earning tens of thousands of dollars in salary. Instead of enforcing strict prerequisite chains, engineering programs should reevaluate and loosen prerequisite chains policies. For example, Calculus I content may not actually be required for Physics I because physics instructors may have already removed complex computations that require calculus (e.g., center of mass and symmetric geometry), because students have traditionally shown poor performance regardless of prerequisite course performance (Faulkner, Earl, & Herman, 2018).

Some may argue that these "redemption" policies lower the academic rigor or inflate the grades of engineering programs. However, if students are retaking exams or courses to earn better grades, these grades indicate that students know more now than they did when they performed poorly. These redemption policies do not lower academic rigor, rather they demonstrate academic rigor, because the redemption policies imply that students may need to retake exams or courses. These redemption policies communicate to students that they may not succeed their first time and that failure is anticipated, just like the engineering design process. Furthermore, these redemption policies can promote the growth mindset.

3.5.6 Potential for targeted interventions for students who experience academic failure

Research has shown that mindsets can change. For example, in one laboratory session, researchers used an intervention to teach struggling first-year college students that poor academic performance was normal, that it did not reflect inability (Wilson & Linville, 1985). A randomly assigned treatment group watched videos of upperclassmen who attributed their poor performance to factors that disappeared over time, such as their unfamiliarity with college classes; they reported that their grades eventually improved. The control group saw videos of same upperclassmen but with no mention of grades. One year later, the treatment group had earned higher grades than the control group. By assuring students that their poor performance could be improved, this intervention for first-year college students helped students avoid adopting the fixed mindset. Research has also shown that goal orientations can change. Some researchers have argued that students with performance-approach goal orientation would focus on surface-level learning strategies to demonstrate ability rather than learning (Midgley, Kaplan, & Middleton, 2001), and that these students have the potential to adopt performance-avoid goal orientation when they experience changes in perceived-competence or the likelihood of failure (Middleton, Kaplan, & Midgley, 2004). In contrast to changes in performance goal orientations, Hoyert and O’Dell (2006) showed that students can benefit from focusing on mastery goals. They offered an intervention to students who had performed poorly on an examination in an introductory psychology course. The intervention aimed to help students adopt mastery goals over performance goals. Hoyert and O’Dell (2006) found that students who had participated in the intervention performed better on subsequent exams than students who had not participated. By adopting a growth mindset and pursuing mastery goals, students may be trained to persist in engineering.

We suspect that interventions that promote the growth mindset would particularly benefit students with Avoidant experiences to help them interpret their failures as learning opportunities. In addition, we suspect that goal orientation interventions and interventions aimed at improving metacognition would particularly benefit students with Unresponsive or Floundering experiences. By adopting mastery goal orientations, students would direct their efforts towards learning over grades. After directing their efforts to learn, students would benefit from improving their metacognition, or “the process of reflecting on and directing one’s own thinking” (National Research Council, 2001, p. 78). Students with poor metacognition have trouble assessing their own learning and performance. Such students would be unable to assess the effectiveness of their study strategies with respect to learning or performance. According to Ambrose, Bridges, DiPietro, Lovett, and Norman (2010), students are poor judges of their own ability, and novice students are much poorer judges of their own ability than advanced students. Therefore, by helping students to improve their metacognition, we could help students with Unresponsive experiences to recognize failure. Furthermore, we could help students with Floundering experiences to recognize that their increased efforts are unproductive. These targeted interventions would help students persist in engineering according to their failure experiences.

3.5.7 Implications for engineering instruction design

Beyond targeted interventions, instructional design can promote learning from failure. Kapur (2016) extensively studied the incommensurability between learning and performance in instruction design. He theorized four possibilities for instructional design that illustrated this incommensurability: productive success, productive failure, unproductive success, and unproductive failure. The following descriptions and examples were taken from Kapur (2016).

Productive success refers to instruction design efforts or conditions that maximize performance in the short term and maximize learning in the long term. Some examples include problem-based learning and guided inquiry. These designs involve scaffolded problem-solving activities to promote initial success in learning. Then the scaffolds are gradually removed as students gain expertise. *Productive failure* refers to instruction design efforts or conditions that may not maximize performance in the short term but in fact maximize learning in the long term. For example, students first engage in solving problems that require concepts they have yet to learn. Then students are instructed on the targeted concepts. “Failure” in this case means that students are typically unable obtain the correct solutions on their own. However, because students are engaging their prior knowledge to generate incorrect solutions to the problem, the failure process prepares students to learn better from the subsequent instruction. *Unproductive success* refers to instruction design efforts or conditions that may maximize performance in the short term without maximizing learning in the long term. That is, there is an illusion of learning in initial high performance. Some examples include teaching strategies that rely mostly on drill-and-practice or rote memorization because students are able to demonstrate standard problem-solving procedures or demonstrate rote recall without conceptual understanding. *Unproductive failure* refers to instruction design efforts or conditions that maximize neither performance nor learning in the short or long term. Some examples include pure discovery learning where students solve problems on their own without any guidance or support whatsoever. There is a lack of long-term learning with discovery learning.

Consistent with the idea of normalizing failure in engineering education, we would recommend instructional designs that promote productive failure. For example, lab courses are prime opportunities for productive failure, where students are encouraged to tinker with experiments and to learn through failure experiences such as troubleshooting and debugging. Sheppard, Macatangay, Colby, and Sullivan (2009, pp. 81-82) claim that engineering labs can promote persistence and optimism, which would also help students persist in engineering. Furthermore, there is even greater potential for productive failure when lab courses are linked to lecture courses, because students can apply course concepts in lab after having just learned them from their lecture. In the absence of lab courses, lecture courses would need to create course structures that would promote productive failure. For example, these course structures can include the frequent formative assessments discussed earlier in *3.5.5 Implications for course and program policies in engineering*.

3.6 Conclusion

Our study explored the experiences of students who persisted in engineering programs after an academic failure. These failures included low exam scores, poor course grades, and awful semesters. Using phenomenography, we constructed four categories of descriptions to characterize students' failure experiences: Unresponsive, Avoidant, Floundering, and Rebounding. The Unresponsive category describes the experiences of students who seem oblivious to failure and do not change their academic behaviors. The Avoidant category describes the experiences of students who become discouraged by their failure and exhibit self-sabotaging academic behaviors. The Floundering category describes the experiences of students who address their failures through increased unproductive effort. The Rebounding category describes the experiences of students who confront their failures and make effective changes to their academic behavior. We also found that students can experience failure differently for different instances of failure.

We caution faculty and administrators against “weeding out” students with Unresponsive and Avoidant behaviors. In reality, the advanced students in our sample (third-year and above) were persisting in engineering despite their Unresponsive and Avoidant experiences. We believe other students with these experiences who receive appropriate support could complete engineering degrees eventually.

Also, our study complements the qualitative study by Meyer and Marx (2014), who investigated the experiences of engineering departers. Taken together, our findings suggest that when students have Floundering experiences during their first and second years in engineering, they are at risk of departing engineering. That is, students can persist through academic failures, but their increased academic efforts to persist can be ineffective and can lead them to further failures that result in departing from their engineering program. For example, in the study by Meyer and Marx (2014), some students were dropped from their engineering programs, because a program policy prohibited degree progression after three failed courses.

Though more research is needed to understand how to help struggling students persist in engineering, our findings suggest that students would benefit from targeted interventions according to their failure experience. Furthermore, our research suggests that engineering programs should revise their course and program policies to promote learning from failure, as in the engineering design process. The implementation of these interventions and the adoption of these policies could nurture the resilience of engineering students and transform the culture of engineering programs to embrace failure as an integral component of engineering education.

Chapter 4

"I AM SMARTER THAN I THOUGHT": TEACHING ENGINEERING STUDENTS HEALTHY LEARNING DISPOSITIONS AND BEHAVIORS

4.1 Introduction

Colleges and universities offer many programs and services to help students succeed academically, and thereby improve student retention. These programs and services include academic advising, living-learning communities, summer bridge programs, and academic support services such as tutoring programs, learning centers, and writing centers (Habley & McClanahan, 2004). However, engineering students have special needs based on the high academic demands of engineering programs. As a result, there are academic support services specifically for engineering students. For example, at the University of Illinois at Urbana-Champaign, the Center for Academic Resources in Engineering offers tutoring, peer mentoring, and collaborative learning opportunities for all undergraduate engineering students (care.engineering.illinois.edu). However, the perception of "helpfulness" of academic support services does not influence students to use them (Young, 2010). Also, some engineering students do not take advantage of academic support services, because they lack personal initiative or believe there is stigma in asking for help (Amenkhienan & Kogan, 2004). Unfortunately, students on academic probation are the least likely to seek and receive assistance (Foreman & Rossi, 1996). In our study, we eliminate the stigma of asking for help by integrating academic support into an academic course. This course could be used for engineering freshman orientation.

Our course encourages students to adopt healthy learning dispositions and behaviors. By *healthy learning dispositions*, we mean attitudes and beliefs that promote learning. By *healthy learning behaviors*, we mean behaviors such as planning, monitoring, and reflecting that enable students to progress toward learning goals. In this study, we developed and evaluated a course, using a design-based research approach, which bridges from laboratory studies on learning to classroom implementation. Following the design-based research approach, we use the Transtheoretical Model of Health Behavior Change to guide our translation of theories related to healthy learning dispositions and behaviors during the design of the course. This course encouraged students to adopt healthy learning dispositions while also teaching some of the cognitive skills typically offered by academic support services.

4.2 Background

We begin this section with some examples of academic success courses for engineering students. Next, we describe the theories that inform healthy learning dispositions and behaviors. Afterwards, we describe design-based research and briefly explain its methodology. Last, we explain the theory of change we used to design our course.

4.2.1 Intervention courses that support success for engineering students

At North Carolina State University, a course called "E298 Engineering Student Success" was developed for students placed on academic warning status based on their first semester grades (Raubenheimer, Lavelle, Leach, White, & Moses, 2011). The course included topics on self-assessment, motivation, goal-setting, study skills, learning styles, time management, organizational skills, stress management, decision making, and discovery of campus resources.

The course helped students increase their grades and academic self-efficacy, but retention outcomes were not consistent. Though the course curriculum, design, and structure were informed by research, the course was not developed with a theory of change.

At the University of Illinois at Urbana-Champaign, a mentoring course called "Student Assisted Guidance in Engineering (SAGE)" was created to retain second-semester engineering freshmen on academic probation (Lee, Marszalek, Medina, & Linnemeyer, 2008). Students attended weekly lectures on academic and professional success strategies and skills and met with mentors (second-year engineering students with GPAs over 3.0) twice a week for mandatory two-hour study sessions and informal activities. Through SAGE, 72.9% of students were retained until their third semester. However, by the end of the third semester, many students were back on probation or had dropped out of the university. Again, though the course design was informed by research, the course was not developed with a theory of change.

In contrast to these studies, our intervention course used a theory of change to inform course design. However, similar to these studies, we used theories of motivation and learning related to helping students succeed. Next, we describe these theories related to healthy learning dispositions and behaviors.

4.2.2 Healthy learning dispositions and behaviors

By healthy academic dispositions, we refer to the growth mindset and mastery goal orientation. By healthy academic behaviors, we refer to self-regulated learning strategies and skills. We briefly discuss the research behind these dispositions and behaviors.

4.2.2.1 Mindset theory

Dweck's Mindset theory (Dweck, 2006) describes the impact of students' beliefs about the "malleability of human characteristics" (Yeager & Dweck, 2012, p. 302). Students with the growth mindset set believe they can change personal characteristics (e.g., intelligence) through effort, whereas students with the fixed mindset believe that such characteristics cannot be changed (Dweck, 2006). Blackwell, Trzesniewski, and Dweck (2007) found that students' mindsets predict their academic performance over time, particularly when they encounter challenging work. Several studies on mindsets suggest that the growth mindset promotes resilience (Dweck, 2006; Yeager & Dweck, 2012).

Several researchers have found that mindset theory can explain behaviors of engineering students. Heyman, Martyna, and Bhatia (2002) found that among engineering students, 72% of women had the fixed mindset about engineering aptitude, but only 46% of men did so. Of women who dropped a difficult course, 100% had the fixed mindset. Of women who persisted through a difficult course, only 61% had the fixed mindset. Stump, Husman, and Corby (2014) showed that engineering students with the growth mindset tended to report that they engaged in collaborative learning and knowledge-building behaviors. By contrast, engineering students who had fixed mindsets were less likely to engage in knowledge-building behaviors. These findings suggest that the growth mindset is a healthier learning disposition than the fixed mindset.

4.2.2.2 Goal orientation theory

According to Dweck (1986), students with the growth mindset adopt mastery goal orientations, whereas students with the fixed mindset adopt performance goal orientations. Mastery-oriented students focus on learning, whereas performance-oriented students focus on performance (i.e., grades) (Kaplan & Maehr, 2007). Performance goal orientation is further divided into performance-approach and performance-avoid goal orientations (Elliot, 1999). Performance-approach-oriented students focus on the possibility of achieving success, whereas performance-avoid-oriented students focus on the possibility of failure and attempt to avoid situations where they may receive evaluations. Mastery and performance-approach goal orientations have been associated with persistence, whereas performance-avoid goal orientation has been associated with avoidance of help-seeking and self-handicapping strategies (Kaplan & Maehr, 2007). Also, despite the positive associations with persistence, performance-approach goal orientations have been associated with negative outcomes such as anxiety and low knowledge retention (Midgley, Kaplan, & Middleton, 2001). Therefore, we consider mastery goal orientation to be a healthier learning disposition than either performance-approach and performance-avoid goal orientations.

4.2.2.3 Self-regulation and metacognition

As mastery goal orientation has been associated with self-regulated learning (Kaplan & Maehr, 2007), we teach metacognition and self-regulation in the course. By self-regulation skills, we mean time management and study skills such as planning, monitoring, and assessing learning goals, whereas by metacognition, we mean the "the awareness and knowledge about one's own thinking" (Zimmerman, 2002, p. 65). In the literature, researchers have tended to use *metacognition*, *self-regulation*, and *self-regulated learning* synonymously (Dinsmore, Alexander, & Loughlin, 2008). The commonality between these three constructs is that "individuals make efforts to monitor their thoughts and actions and to act accordingly to gain some control over them" (p. 404). However, metacognition emphasizes the role of an individual's mind as the trigger for regulatory processes over an environment, whereas self-regulation emphasizes the role of the environment as the trigger for the mind to engage regulatory processes. Self-regulated learning resulted from studies that situated metacognition and self-regulation in the academic context (Dinsmore et al., 2008). Therefore, to avoid confusion, we use the term *metacognition* when students' cognitive awareness triggers regulatory processes, whereas we use the term *self-regulation* when students' environments trigger regulatory processes. Furthermore, we refer to self-regulated learning to include both metacognition and self-regulation for the academic context. We refer to self-regulated learning for healthy learning behaviors.

4.2.3 Design-Based Research

To design and evaluate our intervention course, we used design-based research. Design-based research is a rigorous but flexible methodology for education research that attempts to bridge from theoretical studies on learning, tested in laboratory conditions, to classroom implementation (Sandoval & Bell, 2004). Design-based research differs from traditional laboratory experiments in that design-based research is situated in a real-world context with many uncontrollable confounding factors, whereas laboratory experiments are conducted while limiting these factors (Collins, Joseph, & Bielaczyc, 2004). In design-based research, a theory guides the translation of controlled, laboratory studies into classroom practice. Furthermore, design-based research differs from action research in that design-based research applies theory in real-world contexts, whereas action research attempts to solve an immediate problem that often involves the use of non-research personnel (Wang & Hannafin, 2005).

Design-based research focuses on the design and testing of an intervention (Anderson & Shattuck, 2012). Similar to design practice, design-based research employs iteration to refine an intervention of interest. The outcome of design-based research includes the context-sensitive details of theory implementation, which generate new theories and refine existing ones (Design-Based Research Collective, 2003). Furthermore, “best practice” educational interventions are another outcome of design-based research. For this study, we used the Transtheoretical Model of Health Behavior Change to guide our translation of theories into course design.

4.2.4 Transtheoretical Model of Health Behavior Change

The Transtheoretical Model (TTM) of Health Behavior Change was originally developed to address addictive behaviors like smoking (Prochaska & DiClemente, 1983). TTM is also commonly known as the Stages of Change Model. The name “transtheoretical” implies that the model uses constructs from multiple theories and applies them to explain behavior change. TTM has been used to study a range of health and mental health behaviors: alcohol and substance abuse; anxiety and panic disorders; delinquency; eating disorders and obesity; high-fat diets; AIDS prevention; mammography screening; medication compliance; unplanned pregnancy prevention; pregnancy and smoking; radon testing; sedentary lifestyles; sun exposure; and physicians practicing preventive medicine (Prochaska & Velicer, 1997). These studies have helped develop the core constructs of the model. The core constructs include five stages of change and the 10 processes of change. We briefly explain each of these constructs.

In TTM, there are five stages of change: precontemplation, contemplation, preparation, action, and maintenance (Prochaska & Velicer, 1997). *Precontemplation* is the stage in which people do not plan on taking action in the next six months. *Contemplation* is the stage in which people are planning to change in the next six months. *Preparation* is the stage in which people plan to take action in the immediate future, usually measured as the next month. *Action* is the stage in which people have made overt changes in their lifestyles within the past six months. *Maintenance* is the stage in which people are working to prevent relapse.

Some versions of TTEM have a sixth stage, *termination*, in which people no longer have any temptation to relapse and are confident of their ability to prevent relapse. However, because termination is not practical for a vast majority of people, termination is not emphasized in research (Prochaska & Velicer, 1997). Therefore, we focus only on the five stages of change.

To describe the mechanisms that help people progress through the five stages of change, TTM identifies 10 processes of change: five experiential processes and five behavioral processes. The experiential processes are typically used to promote transitions in the early stages (e.g., from contemplation to preparation), whereas the behavioral processes are typically used to promote transitions in the later stages (e.g., action to maintenance) (Prochaska & DiClemente, 1983). Since these processes are not strictly defined beyond names of constructs, we use the definitions described by Prochaska and Velicer (1997) for all processes except for dramatic relief, for which we use the definition by Norcross, Krebs, and Prochaska (2011).

The five experiential processes are consciousness raising, dramatic relief, self-reevaluation, environmental reevaluation, and social liberation (see Table 4.1). *Consciousness raising* involves increasing awareness about a problem behavior such as causes, consequences, and cures. *Dramatic relief* uses the arousal of emotions such as fear, guilt, or regret that would result from not changing. *Self-reevaluation* encourages people to reflect upon their self-image with or without a particular unhealthy habit. *Environmental reevaluation* encourages people to reflect on how the presence or absence of a personal habit impacts their social environment. *Social liberation* involves increasing social efforts that increase opportunities and alternatives that support behavior change (e.g., smoke-free zones and salad bars).

The five behavioral processes are self-liberation, counterconditioning, stimulus control, contingency management, and helping relationships (see Table 4.2). *Self-liberation* is believing that one can change and making a commitment to change. *Counterconditioning* involves learning healthier, substitute behaviors to counter problem behaviors. *Stimulus control* involves removing cues for unhealthy behavior and adding prompts for healthy behavior. *Contingency management* involves managing consequences for healthy or unhealthy behavior (e.g., rewards and punishments). *Helping relationships* involves finding supportive relationships that motivate healthy behavior change.

Table 4.1: The five experiential processes of change in TTM

Experiential Processes	**Definition**
Consciousness raising	Increasing awareness about a problem behavior such as causes, consequences, and cures
Dramatic relief	Using emotional arousal to face emotions such as fear, guilt, or regret that would result from not changing
Self-reevaluation	Reflecting upon their self-image with or without a particular unhealthy habit
Environmental reevaluation	Reflecting on how the presence or absence of a personal habit impacts one's social environment
Social liberation	Increasing social efforts that increase opportunities and alternatives that support behavior change

Table 4.2: The five behavioral processes of change in TTM

Behavioral Processes	**Definition**
Self-liberation	Believing in that one can change and making commitments to change
Counterconditioning	Learning healthier, substitute behaviors to counter problem behaviors
Stimulus control	Removing cues for unhealthy behavior and adding prompts for healthy behavior
Contingency management	Managing consequences for healthy or unhealthy behavior
Helping relationships	Finding supportive relationships that motivate healthy behavior change

TTM has been occasionally used to study behavior change in an academic setting. To study students on academic probation, Topitzhofer (1996) administered an adapted version of the Processes of Change Questionnaire (Prochaska et al., 1988) to assess students' coping strategies that addressed academic difficulties. The questionnaire was used to assign students to a stage of change. Topitzhofer found that, combined with academic ability, students' stage of change accounted for between 18 and 20 percent of the variance in academic performance. In a different study, O'Brien (2002) applied TTM to academic procrastination. He found that students' stage of change predicted exam preparation, which was fully mediated by academic procrastination. In another study, Grant and Franklin (2007) applied TTM to students' deep, achieving, and surface study strategies. They found that the stage of change was positively correlated with self-efficacy and with a composite score combining deep and achieving study strategies. The stage of change was negatively correlated with the use of surface study strategies. Based on their findings, they claimed that their empirical data supported the applicability of TTM to the academic setting.

However, none of these studies used qualitative methods, and no study has used design-based research to apply TTM to an academic setting.

In our study, we applied TTM to the academic context by creating a course intervention that incorporates the experiential and behavioral processes of change into its course design.

4.2.5 Course design

Our course was called *Engineering the Mind*. The course had two overarching goals: 1) to become aware of how the brain works and how humans behave, and 2) to use the newfound awareness to engage in self-regulated learning. To achieve the first goal, we covered course topics that demonstrated how the brain perceives and interprets information, topics such as optical illusions and magic tricks. Then, to achieve the second goal, students related and applied these topics to their academics. Course activities and assignments were designed to incorporate the TTM processes of change.

For an introduction to each course topic, students usually watched TED Talks, which are online videos from expert speakers on various topics such as education, business, science, tech, and creativity. At other times, students read book chapters. As part of their homework, students watched TED Talks on topics such as human cognition, human behavior, and neuroscience. To ensure the credibility of the videos, we chose TED Talks that were presented with research evidence. TED Talk content was also used to deliver short lectures in the classroom, lasting no more than 20 minutes. The TED Talks were selected to promote the TTM consciousness raising process. Some TED Talks were specifically selected to promote the self-liberation process. For example, one TED Talk explained the power of believing (e.g., growth mindset) through research and how students' beliefs predicted academic outcomes. Based on messages like the power of believing, students were expected to exhibit the self-liberation process towards changing their academic disposition and behaviors.

Beyond TED Talk videos, students engaged in in-class activities where they could personally experience psychological phenomena. For example, students participated in an activity called the “Overconfidence Quiz.” This quiz asked for numerical ranges to answer questions like, “What was Martin Luther King, Jr.’s age at death?” or “What is the length of the Nile River in miles?” The Overconfidence Quiz was used to reveal how people are often overconfident about information that they do not actually know. The quiz had 10 questions, and students correctly answered no more than 7 questions and as few as 1. By having personally experienced (and also having exhibited) overconfidence, an undesired human behavior, students may have felt fear or worry that they could do nothing to change. By eliciting these emotions, these activities were used to incorporate the dramatic relief process.

After in-class activities or short lectures on TED Talk content, students split into small groups to discuss what they had experienced or learned, respectively. For example, students expressed their feelings and concerns regarding limitations on human cognition and examples of undesirable human behavior. Small groups were integrated into the course to promote the helping relationships process by helping students find supportive relationships.

To teach students how to overcome unhealthy procrastination through time management skills, students were assigned to maintain a Strategy Document, which they updated weekly. In their Strategy Document, students would plan their academic goals for the week, monitor their results, reflect on their successes and failures, and adjust their plans for the following week. The Strategy Document was designed to engage students in self-regulated learning and focus on mastery goals. Furthermore, these Strategy Documents were graded only for completion to allow students the flexibility to suit their academic needs. The Strategy Documents were implemented to reveal the unhealthy academic behaviors that students were not previously aware of, further promoting the consciousness raising process. Also, because the typical student often procrastinates, we thought that the Strategy Document would serve as a form of social liberation process where students would have the opportunity to engage in self-regulated learning without being graded on their ability to follow through. Students would also discuss the successes and failures from Strategy Documents in their small groups to further promote the helping relationships process.

To specifically help students overcome procrastination, various strategies were taught through the course. One strategy was to include a “consequence and fail” log in their Strategy Document. For example, as part of their weekly plans, students would log about possible consequences if they were to fail to implement their weekly plans. Then, as part of their reflection, students would report why they failed and the consequences that followed. This log would again further promote the consciousness raising process. Students were also taught strategies using rewards and punishments, to incorporate the contingency management process. They were encouraged to reflect on their ideal study environment, to incorporate the stimulus control process. They were also encouraged to consider how they themselves could be a positive influence for their academic peers, to incorporate the environmental reevaluation process. All these strategies were suggested to be included in students’ Strategy Documents. Overall, the Strategy Document encompassed many strategies to incorporate the counterconditioning process.

In lieu of a final exam, students wrote final papers. These papers took the form of a letter in which students were to write to their high school self. These letters would express the lessons they were learning from the *Engineering the Mind* course that would help their past self in preparing for academics in college. Instructions for all course assignments can be found in Appendix B.

4.2.6 Research questions

To integrate academic support services into a course, we designed the *Engineering the Mind* course using TTM and theories related to healthy learning dispositions and behaviors. To evaluate the course according to these theories, we answer the following research questions:

1) Does the *Engineering the Mind* course help students adopt the growth mindset, mastery goal orientation, and self-regulated learning strategies?
2) How well does the Transtheoretical Model of Health Behavior Change describe changes in students' academic dispositions and behaviors through the course?

4.3 Method

4.3.1 Course implementation and participants

We offered a pilot version of the *Engineering the Mind* course during Spring 2017 as a one credit, second-half semester, eight-week course at a large, public research university. There was only one section with 16 registered students. We tested the surveys, but we do not report the results from the pilot. However, we collected student feedback, and we used the feedback to change the course for Fall 2017. According to student feedback, students wanted more help in addressing procrastination. Therefore, in the fall, we increased the number of one-hour class sessions each week from one to two. We devoted one class session each week to focus on consciousness raising topics. We devoted the other class session to address procrastination by focusing on strategies for self-regulated learning.

The Fall 2017 version was still offered for one credit over eight weeks of the second half of the semester, but we offered two sections of the course. The course was intended for engineering students but was open to students from across the campus. There were nine students in one section and eight students in the other for a total of 17 students. Sixteen students submitted consent forms, which were collected by a graduate student who was unaffiliated with the course. One student did not submit a consent form. The consent forms were sequestered until after final grades were submitted. At that time, we found that 15 students had consented to allow their course assignments and pre- and post-survey data to be used for research. All students were residential, full-time, traditional age students. Their demographics are listed in Table 4.3.

Table 4.3: Demographics of research participants

Pseudonym	Academic Level (year)	Major	Gender	Race/Ethnicity
Albert	Third	Physics	Male	Asian**
Brandon	Second	Engineering Physics	Male	White
Calvin	Transfer (Third) *	Physics	Male	White
Dustin	First	Engineering Physics	Male	White
Erwin	Transfer (Sixth) *	Mechanical Engineering	Male	Hispanic**
Francis	Second	Electrical Engineering	Male	Asian**
Gordon	First	Engineering Physics	Male	Hispanic
Howard	First	Computer Science	Male	Asian
Ian	Second	Computer Science	Male	Asian**
Jimmy	Fifth	Engineering Physics	Male	White
Katie	Transfer (Third) *	Computer Science	Female	Asian**
Lucas	Third	Engineering Physics	Male	White
Michelle	Third	Computer Science	Female	Asian**
Norah	Third	Computer Science	Female	White
Oscar	First	Physics	Male	Asian**

Note:* Transfer students' academic level was determined based on when they graduated high school
** denotes non-native English speaker

4.3.2 Data collection

We collected both quantitative and qualitative data from the course. For quantitative data, we created a survey that included items from mindset theory, goal orientation theory, and self-regulation. Items for mindset theory were taken from Dweck's Implicit Theory of Intelligence Scale and scored on a Likert scale from one through six (Dweck, 2006): four items for the incremental beliefs (growth mindset) and four items for the entity beliefs (fixed mindset). Items for goal orientation theory were taken from the Patterns of Adaptive Learning Scales (PALS) and scored on a Likert scale from one through five (Pintrich, Smith, Garcia, & McKeachie, 1991): five items for the Mastery Goal Orientation (Revised) scale, five items for the Performance-Approach Goal Orientation (Revised) scale, and four items for the Performance-Avoid Goal Orientation (Revised) scale. Items for self-regulated learning were taken from the Motivated Strategies and Learning Questionnaire (MSLQ) and scored on a Likert scale from one through seven (Midgley et al., 2000): twelve items for the Metacognitive Self-Regulation scale (from Cognitive and Metacognitive Strategies) and eight items for the Time and Environment scale (from Resource Management Strategies). In total, there were 42 items. These scales have been used previously for college populations. We administered this survey during the first week of the course (pre-survey) and the same survey during the last week of the course (post-survey). This survey can be found in Appendix B.

For qualitative data, we collected all course assignments: Reaction papers, Reflection papers, Strategy Documents, and Final papers. Students wrote Reaction papers to document their thoughts on TED Talks and other media assigned as homework. Students wrote Reflection papers to document their thoughts on course topic and activities. Students maintained Strategy

Documents to plan and evaluate weekly academic goals. Our research project was approved by the local Institutional Review Board (IRB#17595).

4.3.3 Data analysis

Consistent with design-based research (Anderson & Shattuck, 2012), we used multiple methods to analyze our data. For quantitative data, we calculated the average score for each scale by dividing the total added scores of each item in a scale by the total number of items in that scale. For example, the growth mindset scale had four items, each with a score ranging from one through six (six-point Likert scale), and a student's growth mindset score would be the average score of those four items. Then, we used the Wilcoxon signed rank test with a two-tailed hypothesis to examine any score differences between the pre- and post-surveys. We chose a two-tailed hypothesis, because the one-tailed hypothesis would be able to test in only one direction (i.e., either increase or decrease) between the pre- and post-survey scores. With the two-tailed hypothesis, we could test for both increases and decreases between pre- and post-survey scores and verify that the course was not promoting any negative learning dispositions and behaviors. With our small sample size, we would be able to detect only large differences between pre- and post-survey scores. Also, because our sample size was small, we did not perform an exploratory factor analysis to check the reliability of the various constructs in the survey. However, we did calculate Cronbach's α values to check the reliability of the scales for our administration of the survey.

For qualitative data, we used TTM as our theoretical framework to analyze students' course assignments. We used closed coding using a priori codes based on the stages of change and the 10 processes of change. For our closed coding method, we used hypothesis coding, that is, applying a predetermined list of codes derived from a theory about what would be found in the data (Saldaña, 2013). Using these codes, we identified evidence of students' specific stage of change and evidence of students' engagement with the processes of change. The qualitative results would help us identify what aspects of the course were effective in promoting changes in students' learning dispositions and behaviors.

4.4 Results

4.4.1 Quantitative findings from pre- and post-surveys

Among the students who consented to the research, one student did not complete the pre-survey because she missed the first week of classes. Therefore, she was excluded from this analysis, reducing our sample size from $N = 15$ to 14. All remaining 14 students responded to all items in the pre- and post-survey. We chose a standard significance level of .05. We summarize descriptive statistics from the survey in Table 4.4, and we summarize the results of the Wilcoxon signed rank test in Table 4.5. The values of Cronbach's alpha in Table 4.4 indicate internal reliability of each scale for our administration of the survey. We note that the Time and Environment scale had a low Cronbach's alpha of .58. Also, because our sample size was small, we used the W-statistic rather than the Z-statistic to check for statistically significant differences between pre- and post-survey scores (Wilcoxon, 1945). The W-statistic is the minimum of W_+ and W_-, where W_+ is the sum of positive ranks, whereas W_- is the sum of negative ranks. However, we used the Z-statistic to calculate effect sizes according to Eq. (4.1).

$$\text{Effect size} = |Z| \,/\, \sqrt{(2N)} \qquad (4.1)$$

Furthermore, we calculated the matched-pairs rank-biserial correlation according to Eq. (4.2) adapted from Kerby (2014).

$$r = (W_{-} - W_{+}) / (W_{+} + W_{-}) \tag{4.2}$$

According to Eq. (4.2), the matched-pairs rank-biserial correlation is positive for increases between pre- and post-survey scores and negative for decreases between pre- and post-survey scores.

There was a statistically significant difference between pre- and post-survey scores for only the growth mindset and fixed mindset scales. We calculated large effect sizes for growth and fixed mindset: .54 and .48, respectively. Also, we calculated large, matched-pairs rank-biserial correlations of $r = .90$ and –.80 for growth and fixed mindset, respectively. These results suggest that the course helped students increase their growth mindset beliefs and decrease their fixed mindset beliefs. In contrast, we do not have evidence for statistically significant differences in goal orientation scores or self-regulation scales.

Figures 4.1-4.7 show the box plots, the five-number summary, of pre- and post-survey scores for each scale. The five-number summary includes the minimum, first quartile, median, third quartile, and maximum. The box is drawn from the first quartile to the third quartile. Within the box, the horizontal line indicates the median, whereas the "x" indicates the mean. The whiskers extend to the minimum and maximum pre- and post-survey scores, unless there are outliers, scores that lie 1.5 times the interquartile range below the first quartile or above the third quartile. Outliers are depicted by dots beyond the whisker. In the presence of outliers, whiskers extend to the next minimum or maximum score.

Table 4.4: Descriptive statistics from the pre- and post-survey

	Pre (N = 14)		Post (N = 14)		Reliability (N = 28)
Scales	*Md*	*IQR*	*Md*	*IQR*	Cronbach's alpha
Growth Mindset	3.38	2.13	5.00	1.94	.89
Fixed Mindset	2.38	2.00	1.75	1.06	.96
Mastery Goal Orientation	4.50	0.65	4.60	0.70	.73
Performance-Approach Goal Orientation	2.10	1.45	2.30	1.45	.82
Performance-Avoid Goal Orientation	2.38	0.88	2.50	1.06	.70
Metacognitive Self-Regulation	4.17	0.90	3.96	1.08	.71
Time & Environment	4.25	1.34	4.25	1.56	.58

Md = median; IQR = interquartile range

Table 4.5: Results of the Wilcoxon signed rank test from the pre- and post-survey

Scales (N = 14)	Pre-post score ties	W_+	W_-	W [min (W_+, W_-)]	Critical value of W	Z	p
Growth Mindset	1	4.5	86.5	**4.5**	17	–2.87	.004
Fixed Mindset	1	82	9	**9**	17	–2.55	.011
Mastery Goal Orientation	4	17.5	37.5	17.5	8	–1.02	.308
Performance-Approach Goal Orientation	2	22	56	22	13	–1.33	.184
Performance-Avoid Goal Orientation	1	58	33	33	17	–0.87	.384
Metacognitive Self-Regulation	1	37	54	37	17	–0.59	.555
Time & Environment	4	43.5	11.5	11.5	8	–1.63	.103

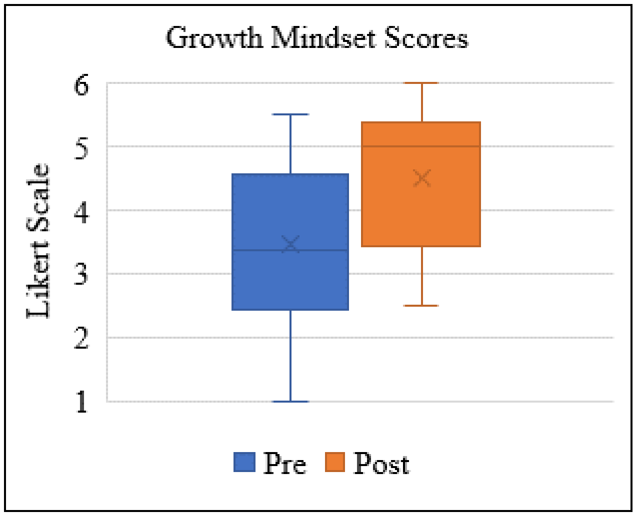

Figure 4.1: Box plot of pre- and post-survey growth mindset scores

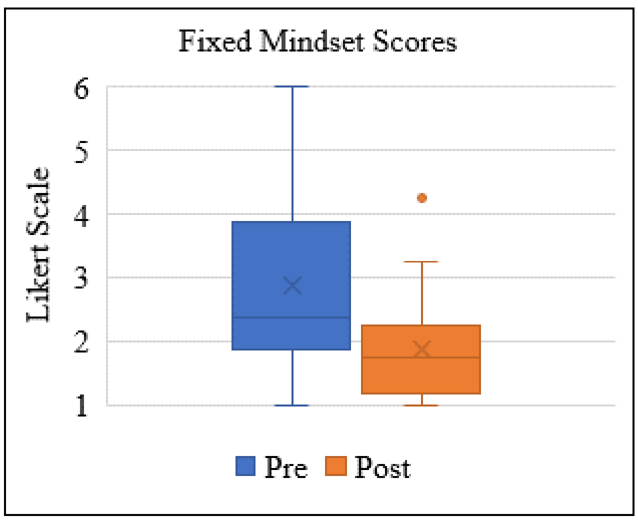

Figure 4.2: Box plot of pre- and post-survey fixed mindset scores

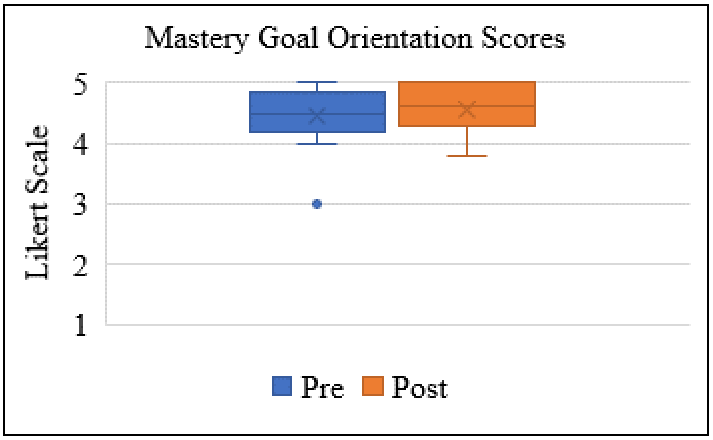

Figure 4.3: Box plot of pre- and post-survey mastery goal orientation scores

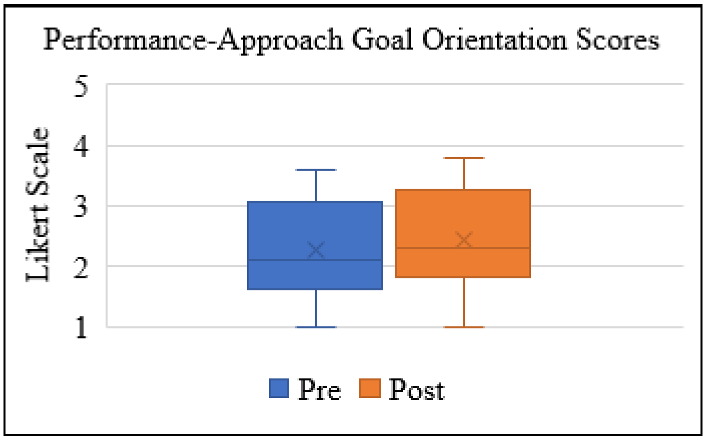

Figure 4.4: Box plot of pre- and post-survey performance-approach goal orientation scores

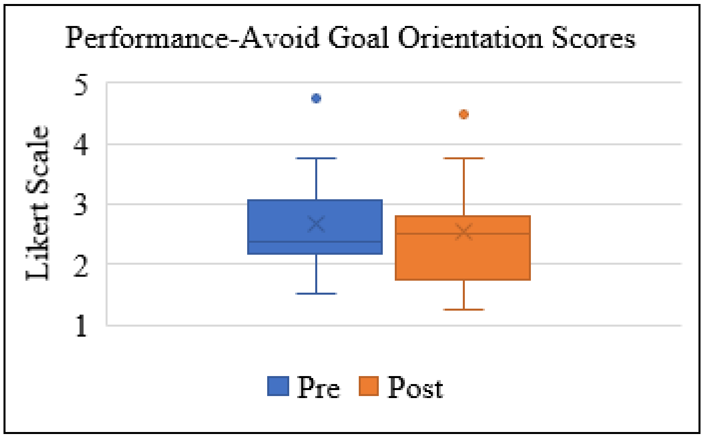

Figure 4.5: Box plot of pre- and post-survey performance-avoid goal orientation scores

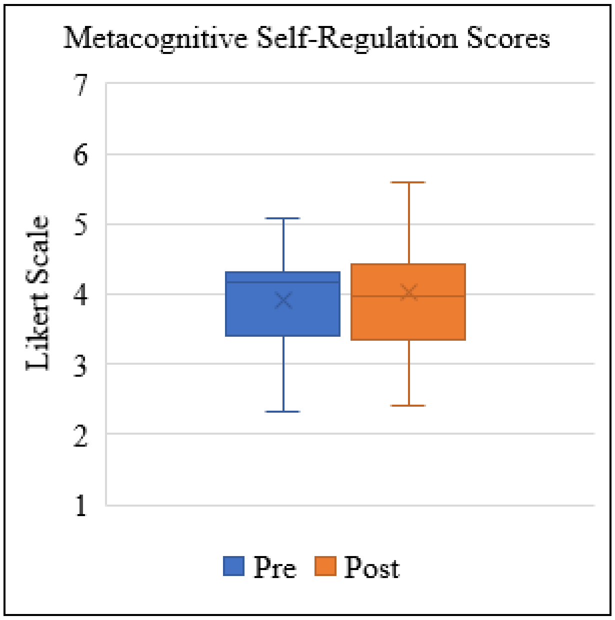

Figure 4.6: Box plot of pre- and post-survey metacognitive self-regulation scores

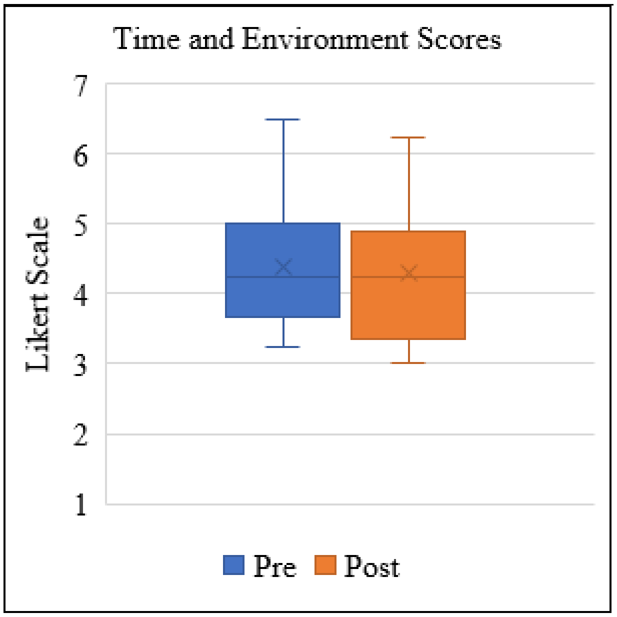

Figure 4.7: Box plot of pre- and post-survey time and environment scores

4.4.2 Qualitative findings

For qualitative results, we describe quotations from students' Reaction and Reflection papers that demonstrated examples of the stages of change and the processes of change. Overall, we have evidence for all five stages of change but not all ten processes of change. For example, we have no evidence of the dramatic relief process. However, some definitions for the processes of change were broadened to accommodate our data that could not be coded using the strict versions of the definitions. We summarize the results of the processes of change in Table 4.6. Furthermore, students' quotations sometimes described multiple processes of change, but we highlight only one process when interpreting the evidence for a specific process of change.

4.4.2.1 Evidence of stages of change

We designed the Strategy Document assignment to invite students into the preparation stage by planning academic goals for each week. We wanted students to apply the self-regulated learning strategies that were discussed throughout the course. Furthermore, we wanted to see whether the assignment would help students transition to the action stage or the maintenance stage. During our analysis, students' Reflection papers revealed that some students failed to follow through on their plans. However, other students described benefits of using the assignment, ranging from an increase in awareness to consistent maintenance of productive academic behaviors. We ordered excerpts below to portray the stages of change related to students' Strategy Documents.

We begin with Howard, a first-year student, and how he realized he did not manage his time well.

> The insights I have gained by doing the strategy document is to show me just how far I am willing to go to make excuses for not starting to do my work. It also has showed

Table 4.6: Summary of the evidence of processes of change in students' course assignments

Processes of change	Original definitions (from Table 4.2 and Table 4.3)	Findings
Consciousness raising	Increasing awareness about a problem behavior such as causes, consequences, and cures	Observed
Dramatic relief	Using emotional arousal to face emotions such as fear, guilt, or regret that would result from not changing	No examples observed
Self-reevaluation	Reflecting upon their self-image with or without a particular unhealthy habit	Broadened definition as reflecting upon undesirable self-image or undesirable conceptions of themselves
Environmental reevaluation	Reflecting on how the presence or absence of a personal habit impacts one's social environment	Observed but not related to academics
Social liberation	Increasing social efforts that increase opportunities and alternatives that support behavior change	Observed
Self-liberation	Believing in that one can change and making commitments to change	Broadened definition to include belief changes without commitments to change
Counterconditioning	Learning healthier, substitute behaviors to counter problem behaviors	Observed
Stimulus control	Removing cues for unhealthy behavior and adding prompts for healthy behavior	Observed
Contingency management	Managing consequences for healthy or unhealthy behavior	Observed
Helping relationships	Finding supportive relationships that motivate healthy behavior change	Observed

me that even though I have a decent amount of time in the week much of it goes to anything but actual productive work.

(Howard)

Howard had a problem with procrastination, as indicated by his "excuses for not starting to do work" and by how "much of [his time] goes to anything but productive work". However, he had not known that he behaved in such a way until he wrote the Strategy Document, indicating that he was in the precontemplation stage before engaging with the Strategy Document. That is, he was not even aware of the problem (procrastination) that he needed to change. After reflecting on his Strategy Document, he became more aware of his procrastination behavior. Though he had made concrete plans each week, we had no evidence that suggested he stopped procrastinating.

Jimmy, a fourth-year student, described how the Strategy Document helped him to eventually overcome procrastination.

> I think that if I am not doing well in a class, it most certainly is worth changing my strategy. Unlike my previous years in undergrad, this class actually forced me to write down my strategy for the first time. I think actually looking at my strategy did help me making it better. I would always tell myself to not procrastinate on my homework but it took several times of actually typing out not to [procrastinate] each week to finally not procrastinate my ENTIRE assignment the night before or day of. Like most things in life, the strategy document is easier said than done.
>
> (Jimmy)

Jimmy was most likely in the contemplation stage, as indicated by his remark: "if I am not doing well in a class, it most certainly is worth changing my strategy." That is, he was at a stage where he would consider change if he thought he was performing poorly in a course. The Strategy

Document eventually helped him take action, though it took him several weeks of planning, as indicated by his remark, “it took several times of actually typing out not to [procrastinate] each week to finally not procrastinate.” By engaging with the Strategy Document, Jimmy transitioned to the preparation stage (i.e., planning each week) and eventually to the action stage (i.e., succeeding in not procrastinating). However, we do not have evidence of whether he sustained this non-procrastinating behavior or relapsed back to procrastination.

Michelle, a third-year student, described how the Strategy Document helped her monitor her academic behavior.

> I’ve learned a lot about how I actually work. I always pictured myself as this very busy, very efficient college student. Analyzing how much free time I had and where I was spending it was an eye opener. I’ve also learned that I work well when I distribute my work load evenly over several days and I am most efficient when I isolate myself from all distractions, such as when I am studying in the [library] study carrels. I’ve also learned that sleeping well really affects my ability and willingness to work.
>
> (Michelle)

It is unclear what stage Michelle was at before she wrote the Strategy Document, but she described herself as a “very busy, very efficient college student.” Her self-description suggested that she was perhaps in the action stage, as someone who takes efficient actions because her life is busy. By engaging with the Strategy Document, she was able to identify the conditions that helped excel, as indicated by her remarks: “I’ve also learned that I work well when I distribute my work load,” and “I am most efficient when I isolate myself from all distractions.” These conditions even extended to her sleep habits. Her self-regulating behavior suggested that she was in the maintenance stage when using the Strategy Document, because she was monitoring her behavior and making adjustments as necessary.

Francis, a third-year student who was not a native English speaker, described how the Strategy Document helped him with self-control and helped him not to procrastinate.

> I have practiced my strategy for 4 weeks (including Thanksgiving break). Using the strategy document, I have known that people, without sufficient self-control like me, can apply both internal and external pressure to keep learning and academics [*sic*] in progress. The part that has helped me the most is the consequence and fail log I wrote to notice me [*sic*] what would happen if I fail to complete my checkpoints. Articulate through hindsight, which I could imagine before consequences actually happen [*sic*], I can keep myself working and do not procrastinate [*sic*] with my homework and assignments.
>
> (Francis)

Like Michelle, it is unclear what stage Francis was in before he engaged with the Strategy Document. However, he described himself as someone "without sufficient self-control," suggesting that he was at least in contemplation stage because he knew he had problems with self-control. After implementing the Strategy Document over four weeks (i.e., starting when the Strategy Document was assigned), he changed from having a problem with self-control to being able to "keep myself working" and "not procrastinate." He was most likely in the maintenance stage when using the Strategy Document, as indicated by the four weeks that he has been consistently implementing his plans.

4.4.2.2 Evidence of consciousness raising

TTM defines consciousness raising as increasing awareness about a problem behavior such as causes, consequences, and cures. In our first example, Dustin related the overconfidence quiz (mentioned previously in the course design subsection) with his experience on a recent test.

> Just last week I had a Physics test that I felt was fairly easy. The questions that I thought were hard I checked over, but I was confident with everything else, so I didn't check those problems. I ended up getting all the tough ones correct and 5 questions that I did not check over wrong. I thought this [overconfidence quiz] was a good activity because it shows us that no matter how confident we are about a lot of things we are not always right. If I have time on my next test I will definitely be checking every question over no matter how confident I am.
>
> (Dustin and the overconfidence quiz)

After the overconfidence quiz, Dustin realized that confidence was not a good indicator for answering correctly on a test. As a result, Dustin resolved to check his answers more carefully on his next test regardless of his confidence, as indicated by his remark "If I have time on my next test I will definitely be checking every question over no matter how confident I am." Dustin's experience with the overconfidence quiz illustrated that the overconfidence quiz effectively incorporated the consciousness raising process to influence his behavior.

In another example, Howard described how the topic on optical illusions influenced his behavior while taking a math quiz.

> I have learned that what I see with my eyes may not actually reflect reality and that what I see has been put through the lens of my past experiences. The awareness of how humans think has changed the way I think by making me more conscious of how

> I perceive the world. I am aware that I see the world through my past experiences so when I am looking at something new I also try to see how my past experiences may be distorting reality. This can be seen when I was talking [taking] a math quiz previously. I was working on practice problems and when I was taking a quiz a similar problem had shows up. Before when I looked at the problem on the quiz I would have thought it was the exact same problem however in reality the coordinate system was different so the graph was in a different plane than the practice problem. Previously I probably would not have realized this difference and would have got the problem [wrong] but by looking at the problem more critically I realized this difference and was able to get the question right.
>
> (Howard and optical illusions)

After learning about optical illusions, Howard became more aware of how he perceives the world, as indicated by his remark, “I am aware that I see the world through my past experiences” and “how my past experiences may be distorting reality.” Then, Howard explained how a problem on a math quiz looked similar to a practice problem he had seen previously. However, upon closer examination, he realized that it was a completely different problem. We interpreted Howard’s following remarks to indicate his thinking process before he had learned about optical illusions: “Before when I looked at the problem on the quiz I would have thought it was the exact same problem,” and, “Previously I probably would not have realized this difference.” Therefore, Howard’s experience illustrated how optical illusions positively influenced his awareness through the consciousness raising process.

Reflecting on the impact of the entire course, Albert described how his weaknesses were revealed.

> This class revealed a lot of my weaknesses, both the ones that I was not aware of, and the ones that I did not like to acknowledge. Now I understand that those weaknesses are common among human, so there is no shame to acknowledge them. Instead, I should be aware of them and deal with them.
>
> (Albert and the course)

Albert became aware of his weaknesses through the course. He was not discouraged by his weaknesses, as indicated by his remark, “there is no shame to acknowledge them.” Rather, he felt obligated to “deal with them.” Albert’s reflection illustrates how the course used the consciousness raising process to help become aware of his weaknesses and motivate him to “deal with them.”

4.4.2.3 No evidence of dramatic relief

TTM defines the dramatic relief process as using emotional arousal to face emotions such as fear, guilt, or regret that would result from not changing. In our course, we designed activities like the overconfidence quiz to elicit negative emotional responses from not changing. However, students’ responses to these activities indicated not the dramatic relief process, but instead the self-reevaluation process, which we describe next.

4.4.2.4 Evidence of self-reevaluation

TTM defines self-reevaluation as reflecting upon one’s self-image with or without a particular unhealthy habit. In our course, students wrote Reaction and Reflection papers to describe their thoughts on course content. Many of their responses included descriptions of self-image. However, these responses did not necessarily focus on a particular unhealthy habit; rather, they focused on undesirable self-image. Therefore, we broadened the definition of self-reevaluation as reflecting upon undesirable self-image or undesirable conceptions of themselves. For example, Norah described how the overconfidence quiz challenged her self-image.

> I liked the overconfidence activity we did in class. I think it changed the way I think about myself because it shows me that sometimes I can be overconfident, and sometimes this overconfidence can backfire (for example, overestimating the knowledge I have on a subject before a test). The activity really challenged my thinking and perception of myself (in a good way). I think it will help me improve my academics, because it has shown me that I should second guess how much I actually know and how much I think I know.
>
> (Norah and overconfidence quiz)

Norah had a self-image of being "overconfident" and noticed how her overconfidence could "backfire," as indicated by her example, "overestimating the knowledge I have on a subject before a test." By reflecting on her overconfidence, she was challenged to change her learning disposition, as indicated by her remarks, "it has shown me that I should second guess how much I actually know and how much I think I know."

In another example, Gordon described how he prided himself in studying minimally before coming to college.

> I have also learned I know very little about learning and not to feel "elitist" about not doing extra work. What matters in the end is that I learn and grasp the material the instructor is presenting to us. I may have been the snobby, kid in school who relished in the fact that I didn't have to study as hard. I never learned how to effectively learn when the time came and I performed poorly on my end of year exams – which

> would've given me lots of credit going into college. I am now okay with taking things slow and learning through TED talks or books about how to learn, improving interpersonal skills, and any other soft skills I haven't touched. There isn't any shame in doing extra work if you improve and become a better person in the end. That is important to me. I want to change and I will.
>
> (Gordon and impact of first three weeks of the course)

Gordon previously held a self-image that described himself as a "snobby kid," because he "didn't have to study as hard." However, he realized that before entering college, he had "never learned how to effectively learn" after he had "performed poorly on […] end of year exams." Through the course, he reevaluated his previous self-image and behavior, as indicated by his remark, "I have also learned I know very little about learning and not to feel 'elitist' about not doing extra work." His reevaluation led to being okay with "taking things slow" and "doing extra work" to "become a better person in the end." Gordon's reflection illustrated how the course had engaged the self-reevaluation process to promote changes in his learning disposition.

In contrast to Gordon, Lucas held the opposite self-image in that he used to think his major was just too hard.

> I used to think about my major as something that was just too hard. In reality, I just was not working hard enough. I would think that I was not as smart as the other kids in my major, but I mistook my laziness for lack of intelligence. Being able to work early on homework and study early for exams makes the whole process so much easier. I still am having trouble noticing every time I try to justify laziness, but I am getting better. It helps to know that I am smarter than I thought I was, all it will take is just work. I think that just working more is so much easier than "getting smarter."

> So, it's bitter-sweet to look at where I am lying to myself, but seems to be a lot more sweet than bitter.
>
> (Lucas and TED Talk on self-deception)

While reflecting on the TED Talk on self-deception, Lucas reminisced about how he had a self-image of not being "as smart as the other kids" in his major. However, through working "early on homework" and studying "early for exams," he realized that academics became "so much easier." After reevaluating his ability, he realized that he was smarter than he thought he was. Lucas's reflection illustrated how he engaged in the self-reevaluation process to change his learning dispositions and behaviors.

4.4.2.5 Evidence of environmental reevaluation but not related to learning

TTM defines environmental reevaluation as reflecting on how the presence or absence of a personal habit impacts one's social environment. The difference between environmental reevaluation and self-reevaluation is that environmental reevaluation focuses on the impact of a habit on one's social environment. We note that students' responses did not include academic examples of environmental reevaluation. Rather, the examples below only include reflections on judging others. For example, Norah reflected on the impact of audio and optical illusions on judging people, which was not related to learning.

> Now I am more aware that not all human interactions are perfect, or can be perfect [*sic*]. Human actions depend on how that human views their environment, and these views can be incomplete, or even wrong, based on external factors (for example, illusions). It really has changed the way I judge actions of others and myself. The awareness of the way humans behave changed the way I think by making me more

> careful and questioning of things I see. Specifically, with the topic of optical illusions, I am now more careful about things I see (and now things I hear thanks to that activity [on audio illusions] in class). I try not to let myself overreact to things I experience now in case of a misunderstanding (for example, having a friend say something and maybe mishearing them).
>
> (Norah and audio and optical illusions)

After learning about audio and optical illusions, Norah realized that perceptions "can be incomplete, or even wrong, based on external factors." As a result, she reevaluated how she interprets what she sees and hears, as indicated by her remark, "I am now more careful about things I see (and now things I hear […])." Furthermore, she reevaluated how she "judges actions of others" and herself, as indicted by her remark, "I try not to let myself overreact to things I experience now in case of a misunderstanding." Norah's reflection illustrated how her newfound awareness of audio and optical illusions helped her reevaluate her judgement of others (i.e., social environment), which led to changing her behavior of "overreact[ing] to things."

Like Norah, Gordon reevaluated how he judged people based on first impressions, which were not related to learning.

> Even though I like to think of myself as an objective person, I am really not. I tend to judge people based on my first impression and I have usually been right, but I have met several people throughout college where I have been absolutely wrong. In fact, one of my best friends appeared to be a "cliquey", "basic", "white" girl. I could not have been more wrong. She had many interests similar to mine [*sic*] the friend group [*sic*] and she seamlessly fit in. Who knew she was a person too? This has made me question the way I judge first impressions and I have begun to admit that they are all

> wrong. It's human nature to judge based on first impressions and I have made an effort to reintroduce myself to people several times so that I get a better judge of the person's character. It has also made me think of how other people perceive me and I do my best to remain consistent with my character because one bad day could leave a bad impression of me on an influential stranger.
>
> (Gordon and TED Talk videos on confirmation bias)

From the TED Talk videos on confirmation bias, Gordon reflected on how he had previously thought he was "an objective person." Gordon's experience with one of his best friends made him reevaluate how he needed to stop judging first impressions, as indicated by his remark, "This has made me question the way I judge based on first impressions and I have begun to admit that they are all wrong." As a result, he "made an effort to reintroduce" himself to people to be a "better judge of the person's character." Furthermore, he made efforts to "remain consistent" with his own character to not leave a "bad impression" on an "influential stranger." Like Norah, Gordon's reflection on the impact of judging people on his social environment exemplified his engagement with the environmental reevaluation process, but his reflection had nothing to do with learning.

4.4.2.6 Evidence of social liberation

TTM defines social liberation as increasing social efforts that increase opportunities and alternatives that support healthy behaviors (e.g., smoke-free zones and salad bars). In the academic context, social liberation can be implemented by institutional mechanisms that encourage healthy academic behaviors. Some examples include providing quiet zones in libraries for individual studying and collaboration rooms for students to work on group projects. Students' descriptions of the opportunities provided by the course and the Strategy Document resembled the social liberation process. For example, Calvin expressed his happiness on implementing the Strategy Document.

> One thing I would like to add is that I am very happy that we are doing the strategy document for a class experiment. I am struggling a great deal in [linear algebra]. This is my first semester here as I transferred from community college, and I am already doing really horribly this semester. I will be lucky to pass all three of my technical classes […], even though these courses aren't particularly hard. My poor academic grades are due to my inability to use my resources and due to improper studying. So I am glad for this upcoming experiment, and I hope this class does really help me. (Calvin and the Strategy Document)

Calvin described the timeliness of creating a Strategy Document, as indicated by his remark, "This is my first semester here as I transferred from community college, and I am already doing really horribly this semester." He welcomed the opportunity to improve through the Strategy Document, as indicated by his remarks, "I am very happy that we are doing the strategy document for a class experiment," and "I am glad for this upcoming experiment." These quotations reflect how Calvin perceived the Strategy Document to be an opportunity to engage in healthy academic behaviors, indicating the social liberation process.

In another example, Gordon described how the course was everything he had expected.

> So far, this class has been everything I've expected it to be. We are learning how to engineer the mind by learning how to learn and how to change the way our mind works. This is good because before the class I was working on these things, but I had no guidance to efficiently learn the things I need to learn to change. I don't know

> what else I would like more from this class because it is exactly what I need. (Gordon and the course after four weeks)

Before the course, Gordan had “no guidance” on how to learn and how to change. Through the course, he was “learning how to learn and how to change.” Furthermore, he described that the course was “exactly” what he needed. For both Calvin and Gordon, they perceived the course and the Strategy Document as opportunities to engage in healthy learning dispositions and behaviors, indicating the social liberation process.

4.4.2.7 Evidence of self-liberation

TTM defines self-liberation as believing that one can change and making commitment to change. However, we believe that the self-liberation process should separate beliefs about the ability to change and the commitment to change. In our course, students learned about research from TED Talk videos to explain people’s ability to change. After students’ beliefs were swayed, their attitudes shifted towards considering change. However, these considerations indicated belief changes without commitment. For example, Lucas reflected on his previous beliefs about the brain.

> I thought it was very interesting to learn this information. I had always heard that our brains are moldable while we are young, but not much after that. However, after watching these videos [TED Talks on neuroscience], it’s clear that our brains can keep generating new neurons. When we saw the video about how changing the way we think changes who we are [TED Talk on placebo effect], I assumed that it applied to behavior. In a sense, our behavior heavily depends on the way we think. If we think something, we will act in a way that reflects it. It seems as if now, that there are

so many reasons to live a positive lifestyle. These past few weeks have really encouraged me to live a healthy lifestyle. I have learned that eating healthy, exercising, cutting out distractions, and starting work early all lead to measurable, actual results. In order to be the best person I can be, I will try to implement these things.

(Lucas and TED Talks on neuroscience and placebo effect)

Based on Lucas's reflection, we see how the TED Talks influenced his attitudes towards behavior change, as indicated by his remarks, "our behavior heavily depends on the way we think" and "If we think something, we will act in a way that reflects it." Furthermore, he believed that these behaviors "all lead to measurable, actual results." However, he said he would "try to implement these things," indicating an attempt at these behaviors rather than commitment. In summary, we can see how Lucas believes that he can change, but there is no indication of commitment to change. Therefore, there is evidence for only the aspect of belief change from the self-liberation process.

In another example, Michelle reflected on the effect of mindsets.

> The talk about mindsets changing bodies [placebo effect] was slightly hard to believe, but there was research evidence backing the study so I'm inclined to believe it. The talk on behavior change was very inspiring. I think that when we change our mindset, we subconsciously also change our behaviour, and the two TED talks [on neuroscience] are more or less talking about similar things. One of the things I found really inspiring about the talk on behavior change is that it gives us a chance to set tangible goals and act on them. It feels like that is something easier to implement. […] I think that it's somewhat harder for me to just "believe" in something and

> change my mindset like that, especially now that I know about the effect of doing that, but it's something I would definitely be willing to try.
>
> (Michelle and TED Talks on neuroscience, placebo effect, and behavior change)

Like Lucas, after watching the TED Talks, Michelle began to believe in the ability to change, as indicated by her remark, "there was research evidence backing the study so I'm inclined to believe it." However, rather than committing to any mindset or behavior changes, she expressed that she "would definitely be willing to try." Lucas and Michelle's reflections illustrated how belief changes were possible without any commitments to change, again indicating only part of the self-liberation process.

4.4.2.8 Evidence of counterconditioning

TTM defines counterconditioning as learning healthier, substitute behaviors to counter problem behaviors. In our course, we taught various ways to overcome procrastination. We also included a video specifically to address this problem called "How to Stop Procrastinating" by Jordan Peterson. In this video, Peterson talked about different ways to think about procrastination. Students' responses to this video described the strategies that were helpful for them. We first look at Katie's response to the video.

> I wouldn't say that this video complete teaches me how to prevent procrastinating and completely enables me to do so. But I did learn something from it. I learned that to make a great difference I need to make up a lot of tiny progress and tiny goal to help achieve the huge goal. I also learned that I need to make each little process handy and approachable. I also need to make each small goal positive so that I feel active and

> enjoyable [*sic*] to make progress toward it and do the works more efficiently.
>
> (Katie and video on "How to Stop Procrastinating")

Katie described how she needs to make "a lot of tiny progress and tiny goal[s] to help achieve the huge goal." She also described how each goal needed to be "positive" to make her "feel active" and enjoy making progress. Katie was learning new ways to overcome and counter procrastination, indicating the counterconditioning process.

In another example, Michelle highlighted strategies from the video that were different from Katie.

> I think the video was helpful. It had several nice tips and ways of looking at procrastination that will help curb it. I really liked the idea of attaching monetary value to every hour we waste because that really helps us realize how much we could be accomplishing with our time. The idea of talking to ourselves like it's a different person whom we can see wasting away their potential is also really interesting. I think that this is really good because people are generally good at evaluating others, and not themselves so much. This would help realize that we could actually be doing a lot more with our time.
>
> (Michelle and video on "How to Stop Procrastinating")

Michelle "liked the idea of attaching monetary value to every hour" wasted. She also liked the idea of "talking to ourselves" as if a person was "wasting away their potential." Katie and Michell's reflections illustrated how students were engaging with the counterconditioning process to overcome procrastination.

<u>4.4.2.9 Evidence of stimulus control</u>

TTM defines stimulus control as removing cues for unhealthy behavior and adding prompts for healthy behavior. For example, a person can remove temptations or add reminders. We first look at Albert who described stimulus control with respect to his study environment.

> The video tells me that the environment is very important to our studying/learning behavior. The study environment, especially the peer pressure can strongly influence our behavior. If we were put in a different studying environment, we could develop a very different studying behavior. I can learn better by constructing a better environment for myself. During the night that I know I should study, probably I should make myself offline from network [*sic*] and games. If I decide that I will only play one game, I probably set an alarm clock to remind myself.
>
> (Albert and TED Talk on behavior change)

Albert highlighted the importance of his environment. He gave an example of how "peer pressure can strongly influence […] behavior" on the study environment. For nights when he "should study," he thought to go "offline from network [*sic*] and games." However, he also thought of an alternative for the times he would decide to "only play one game," that is, to set "an alarm clock to remind himself [to stop]."

In another example, Lucas described stimulus control with respect to procrastination.

> Procrastination is my biggest problem, so if I can start work early and finish work early I will be much better off. I have already started waking up at 8 am every day, but I can change more. Also, I need to work on ignoring notifications. I spend too much time checking my phone when I could be being more productive. Maybe by deleting apps on my phone I will be less inclined to check the websites. It is hard to

> tell what will necessarily work, but I cannot wait to improve my study habits.
>
> (Lucas and procrastination)

Lucas had been working on his sleep schedule to start work early and finish early, as indicated by his remark, “I have already started waking up at 8 am every day.” However, Lucas described how he needed “to work on ignoring notifications.” He specifically thought of “deleting apps” (i.e., removing cues). Albert and Lucas’s examples illustrate how they engaged in the stimulus control process to improve their studying behaviors.

4.4.2.10 Evidence of contingency management

TTM defines contingency management as managing consequences for healthy or unhealthy behavior (e.g., rewards and punishments). For example, consequences include rewards when taking steps toward healthy behavior and punishments when taking steps away from healthy behavior. Some students thought about rewards and punishments because the video on “How to Stop Procrastination” had mentioned rewards and punishments. Also, some students described a strategy called the “consequence and fail log” (previously described in *4.2.5 Course Design*) to think about the consequences of not following their weekly plans and to reflect on why they failed to follow through. We first look at Ian who considered rewards to reduce procrastination.

> Maybe I will add some reward or motivation (i.e., why I need to finish this task tonight. What I will get if I do this?)
>
> (Ian and video on “How to Stop Procrastinating”)

In contrast to rewards, Albert thought about incorporating a punishment system.

> This video makes me think that I should construct a stronger goal on my strategy document. By “stronger”, I mean I should make my goals more specific by splitting it

> into smaller step-by-step goals. It also means that I should build some strong punish system for not completing the goals.
>
> (Albert, and video on "How to Stop Procrastinating")

In a different example, Francis described his experience with the consequence and fail log.

> I have practiced my strategy for 4 weeks (including Thanksgiving break). Using the strategy document, I have known that people, without sufficient self-control like me, can apply both internal and external pressure to keep learning and academics in progress. The part that has helped me the most is the consequence and fail log I wrote to notice me what would happen if I fail to complete my checkpoints. Articulate through hindsight, which I could imagine before consequences actually happen, I can keep myself working and do not procrastinate with my homework and assignments.
>
> (Francis and Strategy Document)

Francis described how the consequence and fail log was "the part that helped […] the most." Ian, Albert, and Francis all illustrate evidence of engaging with the contingency management process by considering strategies such as rewards, punishments, and consequences to reduce procrastination. However, we note that the examples of rewards and punishments weren't specific.

4.4.2.11 Evidence of helping relationships

TTM defines helping relationships as finding supportive relationships that motivate healthy behavior change. In our course, we incorporated small group discussions in class to promote the helping relationship process. Also, course activities were chosen to reveal that the vast majority of people have certain behavioral problems (e.g., audio illusions, optical illusions, bias, overconfidence, etc.). We wanted students to recognize that these behavioral problems were not unique to unlucky individuals but shared by many. The following quotations describe how students viewed the helping relationship process.

In our first example, Calvin found himself having fun with the course.

> I have been having a lot of fun in class recently. I find myself more excited for that than other classes. I really enjoy the in class discussion. I feel comfortable in my group even though I don't really know my groupmates well.
>
> (Calvin)

Calvin described how he was enjoying class discussion and comfortable with his small group, even though the other students were strangers initially. Similarly, Francis described small group discussion as a type of mentoring.

> Class discussion is more like a psychological mentoring between group members in my discussion group. In a small group with 3 members, we usually share struggles and mental stress. Because I wanted to know learning behaviors and advices to handle stress, I think group discussion is the best part of our class.
>
> (Francis)

Francis described his small group discussion as "psychological mentoring" where they could "share struggles and mental stress." To him, small group discussion was the "best part of our class." Francis perceived his small group to be enjoyable and beneficial for him, indicating the helping relationship process.

In a different example, Gordon reflected on the impact the course topics were having on him.

> The TEDTalks on mindset change and behavior change is [*sic*] providing the gentle push I need to become the person I've dreamed of becoming. I'm making gradual improvements every day and I'm learning a lot about this process. This isn't the first time I have changed my behavior, but it is the first time I have been more aware of my behaviors and my actions, because we are actively discussing it in class. It's also comforting to know I am not the only person doing this too.
>
> (Gordon)

We highlight the last sentence in Gordon's quotation, "It's also comforting I am not the only person doing this too." It was important for Gordon to know that he wasn't alone in becoming more aware of his behaviors and actions, indicating the importance of the helping relationship process.

4.5 Discussion

4.5.1 Quantitative findings

To answer our first research question, "Does the *Engineering the Mind* course help students adopt the growth mindset, mastery goal orientation, and self-regulation strategies?" we used the Wilcoxon signed rank test to compare the pre and post scores for each scale on our survey. Our findings suggest that the course helped students to adopt the growth mindset and to reject the fixed mindset. More specifically, the growth mindset scores increased from pre-survey to post-survey, whereas the fixed mindset scores decreased from pre-survey to post-survey. Each change in mindset scores was statistically significant, with a large effect size. For the goal orientation and self-regulation scales, the pre and post score differences were not statistically significant.

With respect to the goal orientation and self-regulation scales, the eight-week course duration may have been too short to significantly influence students' post scores. Specifically, for goal orientations, another explanation is that students' pre-survey scores for the mastery goal orientation scale were already high (see also Fig. 4.3). Therefore, there was no room for students to improve significantly on their post-survey scores for mastery goal orientation. This finding suggests that we did no harm to students' mastery goal orientation, as indicated by the lack of statistically significant decrease in mastery goal orientation scores.

Overall, the increase in growth mindset scores and decrease in fixed mindset scores is a positive outcome. As we mentioned in *4.2 Background*, Stump et al. (2014) found that engineering students with the growth mindset engaged with collaboration and knowledge-building behaviors, whereas engineering students with the fixed mindset were less likely to engage with knowledge-building activities. Perhaps, now our students would be more likely to engage in knowledge-building behaviors than before.

We also previously mentioned that, of female students who dropped a difficult course, 100% of them held the fixed mindset (Heyman et al. 2002). In another study, Paulsen and Wells (1998) found that many students in the physical sciences hold the fixed mindset. Furthermore, when facing difficult courses and low exam grades, engineering students quickly begin to question their ability and their reasons for pursuing engineering (Seymour & Hewitt, 2000). Rather than questioning their abilities or dropping courses, perhaps now our students would be more likely to focus on ways to improve because they more strongly believe in the growth mindset.

4.5.2 Qualitative findings

To answer our second research question, "How well does the Transtheoretical Model of Health Behavior Change describe changes in students' academic dispositions and behaviors through the course?" we analyzed students' course assignments to find evidence for the stages of change and for the processes of change. Based on students' Reaction and Reflection papers, students' quotations illustrated how students were in five stages of change depending on how they engaged with the Strategy Document. Also, students' quotations illustrated how students engaged in a variety of processes of change (summarized in Table 4.6). Specifically, we found evidence for one experiential process of change and all five behavioral processes of change as defined by the original definitions: consciousness raising, social liberation, counterconditioning, stimulus control, contingency management, and helping relationships. In addition, we broadened the definitions for the self-reevaluation and self-liberation processes to fit our data. Also, we observed evidence for the environmental reevaluation process, but students' reevaluations were not related to learning. Last, we did not find any evidence for dramatic relief.

Our qualitative findings complement the quantitative findings from other studies that applied TTM to the academic setting (Topitzhofer, 1996; O'Brien, 2002; Grant & Franklin, 2007). That is, our study provided qualitative evidence to identify students' stage of change and to illustrate how they were engaging in various processes of change, whereas the other studies provided quantitative evidence to correlate students' stage of change with TTM constructs and academic behavior.

The experiential processes of change are often used to help make transitions in the early stages of change. The consciousness raising process was the most prevalent in our data. One explanation for this finding is that the consciousness raising process was most likely the easiest process to incorporate in the course, because students naturally learn new information in their courses. For example, in our course, students were learning new information about human cognition, human behavior, and neuroscience.

In comparison to the evidence for one experiential process of change, we found evidence for all five behavioral processes of change. One possible explanation for this finding is that it is easier to blindly obey than engage in critical reflection. Because students want to succeed in their academics, they are willing to make behavioral changes to help them succeed. However, in our findings, we do not have clear evidence that students actually engaged in these behaviors. Rather, we only have evidence that students thought about these behavioral processes of change. We explain more in *4.5.3 Limitations*.

Regarding the broadened definition for the self-reevaluation process, the original definition limited our ability to code students' responses, because their reflections on their self-image had to be linked with a particular unhealthy habit. Therefore, we broadened the definition to capture students' reflections on unhealthy self-images without the link with a particular unhealthy habit. We describe two possible explanations for why we had to broaden the definition for the self-reevaluation process. One explanation is that TED Talks described how mindsets affect behavior but not the other way around. As a result, perhaps students were primed to engage in the self-reevaluation process using the same pattern of thinking, that is, how their self-image impacts their behavior rather than how a particular unhealthy habit impacts their self-image. Another explanation is that students may not be aware that some of their learning behaviors are unhealthy. For example, in college, students often engage in the same behavior that helped them succeed in high school, and they may not realize that their high school academic behaviors are insufficient for the demands of college. We argue that it is important to broaden the definition of the self-reevaluation process as we have, because students' reevaluations of their self-image can change their learning dispositions in a positive way (see *4.4.2.4 Evidence of self-reevaluation*).

Similar to the reasons for broadening the self-reevaluation process, we broadened the definition for the self-liberation process. Based on the original definition for the self-liberation process, we were limited in our ability to code students' responses, because students had to both believe that they could change and make a commitment to change. Therefore, we broadened the definition to separate students' belief that they could change from their commitment to change. We argue that this separation is important, because believing one can change is not a trivial matter. For example, the whole growth mindset literature suggests that believing one can change is crucial for students' success (Dweck, 2006). Furthermore, although making a commitment is important, making a commitment should be separated from the belief in one's ability to change.

Next, we found evidence for the environmental reevaluation process, but students reflected on how they reevaluated "judging others." Their reevaluation was not related to learning. In our course design, we wanted students to recognize that their positive learning dispositions and behaviors could positively influence their peers. However, we did not find any such evidence in students' Reaction and Reflection papers. One possible explanation for this finding is that students were focused on how others could negatively influence them rather than how they themselves could be positive influences. For example, in *4.4.2.9 Evidence of stimulus control*, Albert mentioned how peer pressure could strongly influence behavior within the study environment.

Furthermore, we did not find any evidence for the dramatic relief process. One possible explanation for this finding is that it is easy to invoke emotions of fear, guilt, and regret with respect to the health context, because health behaviors can be linked with the risk of death. However, in the academic context, it is not quite clear how to invoke the same kinds of negative emotions. For future iterations of the course, we will have to think of other ways to engage students in the dramatic relief process.

4.5.3 Limitations

One limitation of our findings is that we did not design the study to identify the course activities that connected mindset scores with a particular part of the course. We suspect that different course activities were effective for different students, and that different students would have different reasons for why they were effective. For example, in *4.4.2.8 Evidence of counterconditioning*, we see that students adopted different strategies from the "How to Stop Procrastinating" video. However, we did not design our study using sequential explanatory mixed methods where our qualitative results were designed to help explain and interpret our quantitative results. Rather, our qualitative results were designed to find evidence of TTM constructs.

Another limitation of our study was that our qualitative findings were limited to students' written papers. Students' Reaction and Reflection papers required only 200 to 300 words, and most students stopped after achieving the minimum word count. Furthermore, students' responses also depended highly on instructor prompts. Because we were limited to what students wrote in their papers, we could not probe deeper into their thought process regarding course topics and activities. For future work, we will gather more in-depth qualitative data on the impact of the course using individual and focus group interviews.

Another limitation of our study was how students found out about the course. To help recruit students for our second-half semester course, we emailed all the engineering advisors to forward our course information to any students looking for a one-credit course. As a consequence, some students might have just needed one credit to maintain full-time status. Also, we know the physics advisor forwarded the information, because there was a disproportionate number of physics and engineering physics majors who confirmed that they heard about the course through their advisor. If we had a better strategy to advertise our course, we may have had a larger and more diverse sample than our current sample. Last, the course was an elective. As a consequence, students might have started with a stronger interest or motivation that influenced them to engage with the course more than with a required course.

4.6 Conclusion

Our study presents an intervention course developed using a design-based research approach. The course was designed to encourage students to adopt healthy learning dispositions and behaviors. By healthy learning dispositions, we mean the growth mindset and mastery goal orientation, whereas by healthy learning behaviors, we mean behaviors related to self-regulated learning such as planning, monitoring, and reflecting on learning goals. Consistent with design-based research, we used the Transtheoretical Model (TTM) of Health Behavior change to translate theories related the healthy learning dispositions and behaviors into our course design. Based on quantitative pre- and post-survey data, we found that the course increased students' growth mindset scores and decreased students' fixed mindset scores. We found no statistically significant differences with students' goal orientation scores and students' self-regulation scores.

Based on qualitative data using students' written assignments, TTM covered all processes of change identified by students. That is, we found no new processes.

TTM has been primarily used in the health context, but we applied TTM to the academic context. To better fit the academic context, we suggest modifications to two processes of change: the self-reevaluation process and the self-liberation process. We encourage more research that applies TTM to the academic context, and we encourage future intervention courses to be developed using a design-based research approach. Our study demonstrates that theory-informed interventions, like our course, can be effective in helping students adopt healthy learning dispositions.

For future work, we plan to continue evaluating the course and make improvements for each offering of the course. We hope that the course can eventually be offered by other engineering programs. By encouraging students to adopt healthy learning dispositions and behaviors, engineering programs can help students persist in engineering, and these healthy learning dispositions and behaviors will continue to benefit them well into their professional engineering careers.

CHAPTER 5

CONCLUSION

As presented in Chapters 2, 3, and 4, I conducted three studies related to helping students persist in engineering. In Chapter 2, I used binary logistic regression to predict one- and two-year engineering retention using the Grit Scale. Though Grit does predict engineering retention, I would not recommend using Grit to predict engineering retention, because one of Grit's subscales, Consistency of Interest, does not predict retention at all. In Chapter 3, I used phenomenography to construct categories that describe the experiences of students who persisted in engineering despite an academic failure. I constructed four categories: Unresponsive, Avoidant, Floundering, and Rebounding. Engineering students' experiences with academic failure suggest that engineering programs should revise course and program policies to support learning from failure, just as professional engineers learn from failure in engineering design practice. In Chapter 4, I used the design-based research methodology to design and evaluate my *Engineering the Mind* course. According to previous research, when students adopt healthy learning dispositions and behaviors, they are more likely to succeed in their courses and to persist in engineering programs. I used the Transtheoretical Model of Health Behavior Change to translate theories related to healthy learning dispositions and behaviors into the design of the course. The course helped students adopt healthy learning dispositions as indicated by the increase in growth mindset scores and by the decrease in fixed mindset scores. However, the course did not help change students' goal orientation scores. Furthermore, the course did not help students adopt healthy learning behaviors, indicated by the lack of change in students' self-regulation scores. More research is needed to promote the adoption of healthy learning behaviors.

There is no silver bullet in helping students persist in engineering. In principle, “gritty” attitudes and behaviors are preferable to non-gritty behavior in engineering persistence. However, grit alone cannot solve the retention problem. Students cannot simply “work harder”; they also need to “work smarter.” Therefore, I see the problem of helping students to “work harder” separate from the problem of helping students to “work smarter.” For example, engineering students who believe they cannot succeed in engineering may need to actually “work harder”; that is, they need a change in perception of their efforts. Furthermore, I am sure there are plenty of engineering students who persist through academic failures by working harder. These students may benefit from guidance on how to “work smarter”; that is, they need to change their behaviors. I plan to continue researching ways to help students succeed. Helping students succeed is my calling as a teacher, and helping one student at a time is how we change the world.

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APPENDIX A

INTERVIEW PROTOCOL, GOOGLE FORM, AND RESEARCH CONSENT FORM USED IN CHAPTER 3

A.1 Interview protocol

1. Scenario: A high school senior asks you about how to succeed in college.
    - How would you describe success to them?
        - Is that how would you describe success for yourself?
        - If not, how would you describe success for yourself?
            - How would others describe success?
    - What does it look like for you yourself to be considered successful?
        - How do you measure success?
        - What kind of goals do you set for yourself?
            - What are your short-term goals and long-term goals?
        - What happens when you don't meet these goals?
    - What kind of work ethic would you encourage this high school senior?
        - Why did you specifically pick these behaviors?
        - Do you do these yourself?
            - If not, why not?
    - Do you have any successful role models (friends, mentors, famous people, etc) that you take after or want to follow their example?

2. Phrase: "I believe I am able to achieve anything I want if I put in the time and effort"
    - How much do you agree with this phrase?
        - Why isn't it completely true?
    - What other traits would you include to make this phrase truer for you?
        - Why are these traits important to you?

How does this phrase change depending on different contexts: work, relationships, school, etc.?

How much does GPA matter to you?

Why?

What would you do differently if GPA didn't matter?

What stops you from doing what you just said now?

3. Phrase: "I can succeed if I keep learning from my failures"

How much do you agree with this phrase?

What does failure mean to you in this phrase?

Does it affect your long-term goals?

How much does failure discourage you?

What would you do to evaluate your failures?

Do you actually do what you just said?

What would you do if you didn't know how to evaluate your failures?

Do you feel like you have control over the factors of failure?

What factors do you believe you can control? (provide examples)

What factors do you believe you can't control? (provide examples)

What are some failures you've experienced in the past?

What have you actually done in the past regarding your failures?

What you would have like to have done?

4. Scenario: Imagine you're in a senior level engineering class and none of your friends are in that class. You've heard it's very difficult. You look through the syllabus and confirm that it would not be an easy class.

What would be your strategy for succeeding in this class?

Why?

What other strategies would you use?

Do you actually use these strategies? (provide past experience)

What is an easy class and what is a difficult class?

How can you make a class easier for yourself?

Do you actually do this? (provide past experience)

How would you respond if you did poorly on your first exam?

How would you respond if you did poorly, again, on your second exam?

Do you actually do what you just said? (provide past experience)

Would you drop the class?

What if graduation was in jeopardy?

Did you expect to succeed after responding to your first failure?

How would you respond if you failed the class?

Would you take the class again?

Why?

Would you go to the professor?

How would you recommend someone to go through failure well?

5. Scenario: Imagine you're in a class that you are interested in but you find yourself performing less than desired.

How would you explain your lack of performance?

Do you believe you could do better if you tried harder?

When would you give up?

How can your priorities explain your lack of performance?

Would you continue the class to learn the material or consider dropping the class?

Do you have an experience to relate to this?

How would your responses change if the class was in engineering or not?

Do you have an experience to relate to this?

6. Scenario: Imagine you're in a two-person project.

What kind of person would make a good teammate?

How do you compare yourself with others in terms of being a good teammate?

Do you consider yourself a hard, diligent worker? (provide past experience)

Why?

What are things worth working hard for? (provide past experience)

Why?

Are there any particular projects or goals that you'd like to accomplish outside of school?

What are some things you do?

What are some things you'd like to do?

7. Scenario: Since childhood, you wanted to be a <u>*insert future career here*</u>. But once you study to become "said career", you realize you no longer want to pursue this career.

First of all, what would this career be?

What interested you into choosing this career?

What would cause a change of heart?

What would you do if that dream was crushed?

A.2 Google form

Interest in Interview Participation

* Required

What is your email address? *

What is your NetID? *

What is your First Name? *

What is your Last Name? *

Are you persisting in engineering after you earned a D or an F in a required physics, math, computer science, or engineering course? *

- yes
- no

May I contact you to set up an interview? *

- yes
- no

Comments?

Submit

Never submit passwords through Google Forms.

A.3 Research consent form

Purpose and Procedures: The purpose of this research is to understand the academic mindsets and attitudes of students who persist in engineering. This research is being undertaken by the College of Engineering in hopes to improve the quality of engineering education. The investigators include Professor Raymond Price, Professor Michael Loui, and Dong San Choi from the University of Illinois at Urbana-Champaign.

Participants from the College of Engineering will participate in a one-hour, semi-structured interview regarding their academic mindsets and attitudes, particularly on effort and success. All personal identifying information will be kept confidential.

Requirements: All participants must be at least 18 years old.

Participation is Voluntary: Participation in this research is voluntary. The decision to participate, decline, or withdraw from participation will have no effect on your grades at, status at, or future relations with the University of Illinois.

Benefits and Risks: As a result of participating in the study, participants will help us understand engineering students regarding their thought processes to create an intervention to help future students who may struggle in engineering. Risks are expected to be minimal, no more than in everyday life.

Compensation: There will be a compensation of $10 for participation in this study.

Confidentiality: Interviews will be audio recorded and analyzed by Dong San Choi. Results from this research will be published in relevant engineering education conferences and journals. In the event of publication of this research, no personally identifying information will be disclosed.

Whom to Contact with Questions: Questions about this research should be directed to Dr. Price (price1@illinois.edu). If you have any questions about your rights as a participant in this study or any concerns or complaints, please contact the University of Illinois Institutional Review Board at (217) 333-2670 (collect calls will be accepted if you identify yourself as a research participant) or via email at irb@illinois.edu.

I certify that I have read and understand what has been stated in this form.

____ I agree to be audio recorded for the interview.

____ I do NOT agree to be audio recorded for the interview.

____Print Name ___________ Date (mm/dd/yyyy)

____ Signature ___________ NetID

I L L I N O I S

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

APPENDIX B

COURSE SYLLABUS, SURVEY, COURSE ASSIGNMENT INSTRUCTIONS, AND RESEARCH CONSENT FORM USED IN CHAPTER 4

B.1 Course syllabus

ENG199 EM1 & EM2: Engineering the Mind Fall 2017

	EM1	**EM2**
Days:	Mon/Wed	Mon/Wed
Time:	12-12:50 PM	3-3:50 PM
Room:	1103 Siebel Center	106B3 Engineering Hall

INSTRUCTOR

PhD Candidate, Electrical and Computer Engineering

Dong San (DS) Choi: choi88 [AT] Illinois [DOT] edu

Office hours: TBD and by appointment

PREREQUISITE

None

CREDIT

One semester hour

PURPOSE

The purpose of this course is to help you succeed academically by engineering your mind. To achieve this, we first explore how the brain works, the way it perceives and interprets information. For example, we demonstrate how our brain uses shortcuts to visual stimuli, resulting in optical illusions. Then we apply what we know to regulate how we learn. For example, you will apply some of the strategies discussed in this course to your one of your other courses this spring. We will tackle questions such as “How do my prior experiences affect my ability to succeed?” and “How do my beliefs about intelligence affect my grades?” By showing you a whole new world, we hope you will realize your unlimited potential to grow as a person and an engineer. By the end of the course, you will better understand how your brain works, and you will have the skills and strategies to improve the way you learn.

LEARNING OBJECTIVES

1) Learn about psychological phenomena by personally experiencing classic psychology experiments, for example, optical illusions
2) Learn about the brain's heuristics and biases by engaging in classic behavioral economics experiments, for example, gambler's fallacy
3) Learn about how the brain learns through physiochemical processes, for example, neuroplasticity
4) Learn about research that connects attitudes about learning with academic success, for example, mindset and goal orientation theory
5) Learn about self-regulation skills and strategies to develop better studying and learning habits

LEARNING OUTCOMES

1a) Students will be able to identify and relate examples of psychological phenomena in their daily life experience

1b) Students will evaluate these experiences to make more informed decisions pertaining to their study habits

2a) Students will be able to identify and relate examples of cognitive biases in their daily life decisions and interactions

2b) Students will evaluate their life decisions to make more informed decisions pertaining to their studying and learning habits

3) Students will be able to evaluate their studying habits with respect to the brain's physiochemical learning process

4) Students will be able to compare and evaluate their personal beliefs about learning with respect to mindset and goal orientation theory.

5a) Students will be able to relate what they know about how the brain works to justify which self-regulation strategies they use

5b) Students will be able to evaluate the strategies they have used to adapt to their learning environment

CLASS STRUCTURE

Class will consist of a combination of short lectures, videos, in-class activities, and/or discussions – whatever it takes to keep you engaged and wanting more. We will have short lectures will last no longer than 20 minutes. There will be in-class polling during the lectures that can be answered using a computer or your phone. Following these short lectures, we will have small group discussions to personalize what we've learned. The purpose of small group discussion is to help you get to know one another and to help you develop your thoughts regarding course topics. These discussions will help you complete your written assignments (see below), and so, it's in your best interest to engage with your classmates.

HOMEWORK ASSIGNMENTS

Homework will consist of three different types of written assignments that are designed to help you relate the week's topic in multiple ways: reflection papers, reaction papers, and strategy documents. By engaging in the topic throughout the week, you will better retain what you learned rather than forgetting what you learned immediately after you finish the assignment. These written assignments will be turned in online through Compass2g (compass2g.illinois.edu). All assignments will be due at 11:59:59 PM the day before the next class meeting. For example, if there was homework assigned on Monday, the due date will be Tuesday night because the next class meeting is on Wednesday. If there was homework assigned Wednesday, the due date will be Sunday night. As this is a 1-credit course over 8 weeks, homework will average around 4 hours per week. You can expect one reflection paper, one reaction paper, and one strategy document per week.

- In-Class Surveys

You will take surveys regarding your mindset, goal orientation, and self-regulation. These will be done in class. The survey will be administered once in the beginning for diagnostic purposes and once at the end for comparison purposes. These are required for the course but they are not used for grading purposes. The instructor will provide feedback regarding your results.

- *Reflection Paper* (200-300+ words, 5 points each)

Each week, you will write a short paper reflecting on what you learned in class. I will provide reflection questions each paper to help you get started. The purpose of these reflections is to relate what you have learned in class to your personal life. You are highly encouraged to write above and beyond the prompts provided. I hope you will engage in deeper thinking as you reflect by considering the impact of what you have learned to various areas of your life. These will be assigned Wednesday and due the following Sunday night.

- *Reaction Paper* (200-300+ words, 5 points each)

To help you become familiar with new topics, I will assign media content to read or view each week. Similar to the reflection papers, I will provide reaction questions to accompany the reading/media content to help you get started. You are highly encouraged to write above and beyond the prompts to fully capture your reactions to the media content. The purpose of this assignment is to help sort out your thoughts before participating in discussions in class. These will be assigned on Monday and due the following Wednesday night. You should bring a copy of this paper to class to aid you in your discussions. *See the attached Media Reaction Example.*

- *Strategy Document* (no word limit, graded on completion, 5 points each week)

Each week, you will document the process of applying what you learn to your academic goals. This documentation process will allow you to ground your plans and strategies with objective reasons. Your classmates will provide feedback on your plans and strategies so that you may reduce biased reasoning. I expect that you will make changes to your plans and strategies as you learn more about how the brain works. You will then justify the changes you make to your plans and strategies by reflecting on why you made those changes. You will be given time during small group discussions on Wednesday to work on your strategy document but each iteration will be due the following Sunday night to track your changes.

GRADING RUBRIC FOR REFLECTION AND REACTION PAPERS (5 points total per assignment)

1 pt - Wrote about specific content that caught the student's attention

1 pt - Student reflected on how the content related to his/her life

1 pt - Student reflected on how the content related to other people

1 pt - Wrote about how the content related to other areas of life, e.g. academics

1 pt - Wrote more than 200 words

FINAL PAPER (1000+ words, 30 points)

In lieu of a final exam, you will write a final paper synthesizing what you learned throughout the course. Review your written assignments throughout the semester to piece together your thoughts. What do you know now that you didn't know before? What would you do differently now regarding how you study? How has your attitude or mindset changed from the time before you enrolled in the course until now? Specific instructions will be provided later in the course.

FINAL GRADES

Final grades will be determined by the completion of the homework assignments, attendance, and the final paper. Each homework assignment will be worth 5 points (for a total of 15 points each week). Attendance will be worth 1 point for every 15 minutes of class (for a maximum of 6 points each class). As you can see based on the points, you will have a 5-minute grace period in the case you are running late. Arriving later than 5-minutes, however, will results in point deductions. The final paper will be worth 30 points.

- Example Scenario

There will be fourteen classes over the eight weeks. You can earn a maximum of 90 points based on homework assignments (assuming 3 assignments per week over 6 weeks at 5 points per assignment), a maximum of 42 points based on attendance (3 attendance points per class), and a maximum of 30 points based on the final paper. In total, 157 points are available. We will use the standard grading cutoffs: A-plus (96.7%) = 151, A (93.3%) = 146, A-minus (90%) = 141, B-plus (86.7%) = 136, B (83.3%) = 130, B-minus (80%) = 125, C-plus (76.7%) = 120, C (73.3%) = 115, C-minus (70%) = 109, D-plus (66.7%) = 104, D (63.3%) = 99, D-minus (60%) = 94, F (<60%) = less than 94. The total amount of points used to determine the cutoffs will be lowered if you have excused absences and/or assignments.

COLLABORATION

I highly encourage you to discuss what you learned in this course with other people, especially your classmates. I believe the course will be more beneficial to you the more you bounce ideas with one another. However, as the assignments are all based on your own ideas, I expect what you turn in to be your own work. It is fine to reference the conversations you've had with your classmates and/or other people but it should be clear that what you turn in represents your own work. You may not copy someone else's response directly. Please also read the ACADEMIC INTEGRITY section.

LATE SUBMISSIONS

As mentioned previously, each homework assignment will be due on at 11:59:59 PM the night before the next class meeting. For every day they are submitted after the deadline, 1 point will be deducted from the assignment. For example, if an assignment is turned in at 12:00 AM Monday, the assignment will be worth 4 out of 5 points. Similarly, the assignment will be worth 3 points on Tuesday, 2 on Wednesday, 1 on Thursday, and 0 for submissions on or after Friday.

MAKE-UP POLICY AND SPECIAL CONCERNS

For any **excused** absences, your instructor will inform you on what you've missed in class. Unfortunately, you will have missed the in-class experience. However, you will still be able to complete written assignments for the week. You must provide documentation from a professional, like a physician or a dean, to accompany your excused absence. The total amount of attendance points you can earn will be appropriately adjusted to reflect your excused absence(s).

For any **unexcused** absences, you will receive a zero for attendance for that day. However, you will still be allowed to make up the points through an additional written assignment designated by the instructor within one week of the absence.

To make up any assignments, you must make an appointment with the instructor. If there are any unexpected circumstances or situations that arise due to factors such as a disability or a religious practice, please let the instructor know ahead of time.

CLASS ETIQUETTE

- Be on time! I hope that this class will be so entertaining that you want to be here on time.
- Electronics are permitted only for use in class activities (e.g., in-class polls)
- Be respectful to one another! An idea can be questionable, but a person can't be wrong because people change.

COMMUNICATION

- Compass2g will be used to turn in assignments. Please check to make sure you have access to the course on Compass2g (compass2g.illinois.edu).
- Email is the best way to reach me and I will get back to you no later than 24 hours.

ACADEMIC INTEGRITY

- The University of Illinois expects all students to conduct their academic work with high ethical standards.
- All written assignments should represent your own work. You are free to discuss the assignment with other students, and discussion is highly encouraged!
- Violation of these standards of academic integrity will result in appropriate disciplinary action.

RECOMMENDED TEXTS

Readings are drawn from the following books.

- J. D. Bransford, A. L. Brown, and R. R. Cocking, *How People Learn: Brain, Mind, Experience, and School*, National Academy Press, 1999.
- C. Dweck, *Mindsets: The New Psychology of Success*, Ballatine Books, 2007.
- D. Kahneman, *Thinking Fast and Slow*, Farrar, Straus and Giroux, 2013.
- J. Medina, *Brain Rules: 12 Principles for Surviving and Thriving at Work, Home and School*, Pear Press, 2014.

SCHEDULE

Week	Lesson	Topic(s)	Reading/Media Content	Assignments
#1 Oct. 23	Introduction	- Overconfidence Effect	- Optical illusions show how we see (Beau Lotto)	Reflection Paper Reaction Paper Strategy Doc Pre-Survey
#2 Oct. 30	Interpreting Reality (Part 1) - Seeing is Believing?	- Optical Illusions - Inattentional Blindness	- The art of misdirection (Apollo Robbins) - Unbelievable Misdirection (Steven Bridges)	Reflection Paper Reaction Paper Strategy Doc
#3 Nov. 6	Interpreting Reality (Part 2) - Is It Just in My Head?	- Misinformation - Auditory Illusion - Fake Memory	- The power of believing that you can improve (Carol Dweck) - Brain Rules Ch5 – Every brain is wired differently	Reflection Paper Reaction Paper Strategy Doc
#4 Nov. 13	The World Through a New Lens	- Survey results - Mindsets - Mastery and Performance Goal Orientation	- After watching this, your brain will not be the same (Lara Boyd) - You can grow new brain cells. Here’s how (Sandrine Thuret)	Reflection Paper Reaction Paper Strategy Doc
#5	Thanksgiving	Break		
#6 Nov. 27	Engineering the Mind	- Neuroplasticity - Learning Strategies	- Why you think you’re right even when you’re wrong (Julia Galef) - Why we are wrong when we think we are right (Chaehan So)	Reflection Paper Reaction Paper Strategy Doc
#7 Dec. 4	Interpretation Gone Wrong	- Behavioral Economics - Cognitive Bias	- Using our practical wisdom (Barry Schwartz)	Reflection Paper Reaction Paper Strategy Doc
#8 Dec. 11	The Future and You	- Who do you want to be		Post-Survey Final Paper

B.2. Survey

Please answer survey items as honestly as possible because the diagnostic will be more useful to you if you choose to answer honestly. We will go over the interpretations of the results in class. This survey is used for the course as a diagnostic tool regarding your mindset, goal orientations, and self-regulation. Your course instructors will process and return the results. However, course instructors will not know whose name is linked to identification codes so as to protect your anonymity. There is a total of 42 items.

1. It's important to me that I don't look stupid in class.

1	**2**	**3**	**4**	**5**
NOT AT ALL TRUE		SOMEWHAT TRUE		VERY TRUE

2. It's important to me that other students in my class think I am good at my class work.

1	**2**	**3**	**4**	**5**
NOT AT ALL TRUE		SOMEWHAT TRUE		VERY TRUE

3. It's important to me that I learn a lot of new concepts this year.

1	**2**	**3**	**4**	**5**
NOT AT ALL TRUE		SOMEWHAT TRUE		VERY TRUE

4. One of my goals in class is to learn as much as I can.

1	**2**	**3**	**4**	**5**
NOT AT ALL TRUE		SOMEWHAT TRUE		VERY TRUE

5. One of my goals is to show others that I'm good at my class work.

1	**2**	**3**	**4**	**5**
NOT AT ALL TRUE		SOMEWHAT TRUE		VERY TRUE

6. One of my goals is to master a lot of new skills this year.

1	**2**	**3**	**4**	**5**
NOT AT ALL TRUE		SOMEWHAT TRUE		VERY TRUE

7. One of my goals is to keep others from thinking I'm not smart in class.

1	**2**	**3**	**4**	**5**
NOT AT ALL TRUE		SOMEWHAT TRUE		VERY TRUE

8. It's important to me that I thoroughly understand my class work.

1	**2**	**3**	**4**	**5**
NOT AT ALL TRUE		SOMEWHAT TRUE		VERY TRUE

9. One of my goals is to show others that class work is easy for me.

1	**2**	**3**	**4**	**5**
NOT AT ALL TRUE		SOMEWHAT TRUE		VERY TRUE

10. One of my goals is to look smart in comparison to the other students in my class.

1	2	3	4	5
NOT AT ALL TRUE		SOMEWHAT TRUE		VERY TRUE

11. It's important to me that I look smart compared to others in my class.

1	2	3	4	5
NOT AT ALL TRUE		SOMEWHAT TRUE		VERY TRUE

12. It's important to me that I improve my skills this year.

1	2	3	4	5
NOT AT ALL TRUE		SOMEWHAT TRUE		VERY TRUE

13. It's important to me that my teacher doesn't think that I know less than others in class.

1	2	3	4	5
NOT AT ALL TRUE		SOMEWHAT TRUE		VERY TRUE

14. One of my goals in class is to avoid looking like I have trouble doing the work.

1	2	3	4	5
NOT AT ALL TRUE		SOMEWHAT TRUE		VERY TRUE

NOTE: #15-22 have options from 1 through 6

15. You have a certain amount of intelligence, and you really can't do much to change it.

1	2	3	4	5	6
STRONGLY DISAGREE					STRONGLY AGREE

16. Your intelligence is something about you that you can't change very much.

1	2	3	4	5	6
STRONGLY DISAGREE					STRONGLY AGREE

17. No matter who you are, you can significantly change your intelligence level

1	2	3	4	5	6
STRONGLY DISAGREE					STRONGLY AGREE

18. To be honest, you can't really change how intelligent you are.

1	2	3	4	5	6
STRONGLY DISAGREE					STRONGLY AGREE

19. You can always substantially change how intelligent you are.

1	2	3	4	5	6
STRONGLY DISAGREE					STRONGLY AGREE

20. You can learn new things, but you can't really change your basic intelligence.

1	2	3	4	5	6
STRONGLY DISAGREE					STRONGLY AGREE

21. No matter how much intelligence you have, you can always change it quite a bit.

1	2	3	4	5	6
STRONGLY DISAGREE					STRONGLY AGREE

22. You can change even your basic intelligence level considerably.

1	2	3	4	5	6
STRONGLY DISAGREE					STRONGLY AGREE

NOTE: The remaining questions have options from 1 through 7. <u>Also, think of the class that you are struggling with or would like to improve in.</u>

23. During class time I often miss important points because I'm thinking of other things.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

24. I usually study in a place where I can, concentrate on my course work.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

25. When reading for this course, I make up questions to help focus my reading.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

26. When I become confused about something I'm reading for this class, I go back and try to figure it out.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

27. I make good use of my study time for this course.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

28. If course materials are difficult to understand, I change the way I read the material.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

29. I find it hard to stick to a study schedule.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

30. Before I study new course material thoroughly, I often skim it to see how it is organized.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

31. I ask myself questions to make sure I understand the material I have been studying in this class.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

32. I try to change the way I study in order to fit the course requirements and instructor's teaching style.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

33. I often find that I have been reading for class but don't know what it was all about.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

34. I try to think through a topic and decide what I am supposed to learn from it rather than just reading it over when studying.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

35. I have a regular place set aside for studying.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

36. I make sure I keep up with the weekly readings and assignments for this course.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

37. I attend class regularly.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

38. When studying for this course I try to determine which concepts I don't understand well.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

39. I often find that I don't spend very much time on this course because of other activities.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

40. When I study for this class, I set goals for myself in order to direct my activities in each study period.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

41. If I get confused taking notes in class, I make sure I sort it out afterwards.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

42. I rarely find time to review my notes or readings before an exam.

1	2	3	4	5	6	7
NOT AT ALL TRUE						VERY TRUE

B.3 Course assignment instructions

Final Paper, 1000+ words

- You will write a letter to a high school version of yourself (or to someone that you know that is currently in high school).
- In the letter, you will write about how this class has influenced what you wish you had known before coming to college about studying, about yourself, about the world, among other things.
- Consider: small group discussions, reflection papers, reaction papers, strategy documents, and Ask me anything (AMA) times
- Powerpoint slides are attached in your email
- Below are reflection questions from each week as well as the TEDTalks + reaction questions

Lesson 1 – Introduction: Overconfidence Effect

HW1a:

- List all the factors that you consider to be important for learning.
- Explain why each factor is important. There is no real constraints for this homework, but if you want an estimate on length, think about your top 5 most important factors for learning (and explain why).
- If you have additional ones, feel free to share those, too.

HW1b:

- How many hours/week do you spend a week on academics (remember to include your credit load)?
- How many hours/week do you spend on necessary activitie, like sleep, morning rituals, commute, eating, errands/chores, RSO/club activities?
- Identify the "time sink" activities that you do in your free time, and determine how many hours/week you spend on them.
- Why are these "time sink" activities important to you?
- Which of these "time sink" activities would you be willing to give up for academics? Why or why not?

Reflection1:

- What do you think about story time?
- How did you find out about this course?
- What do you think about the overconfidence activity we did in class? How has this activity changed the way you think about yourself? Do you think that knowing this can help you improve your academics? (You can include the intelligence/attractiveness rating activity as well.)
- Do you think the average person would benefit from knowing about the overconfidence effect? Why or why not?

Reaction1:

- Watch Optical illusions show how we see - Beau Lotto
- How has this video changed the way you think about interpreting what you see in the world?
- Do you think that this applies to the classroom? Why or why not?

Lesson 2 – Interpreting Reality Part 1: Seeing is Believing? [Optical Illusions]

Reflection2:

- How has the topic of optical illusions changed the way you think? Explain why or why not?
- Has this topic changed the way you think about visual information?
- Do you think that we are victims of our brain or do you think we can change? Why or why not?
- Does this topic of optical illusions change the way you will engage in visual information in your classes or in your studies? Why or why not?
- If you have answered "No" about having been affected by this topic on optical illusion, take a "Yes" perspective instead and try to find merits to your claims.
- Do you think that this topic will be useful for you in the future?

Reaction2:

The art of misdirection | Apollo Robbins AND Unbelievable Misdirection with Tom Scott

- How does it make you feel now that you know that you can miss information even when you are paying attention?
- Were you able to follow all the tricks? If you want, keep watching the videos again and try to figure out how both performers did their tricks.
- Do you feel that your professors sometimes try to trick you as well? What if they aren't? What if they are bad at giving you clear directions (instead of misdirection)?
- How has this video changed the way you think about paying attention?

Lesson 3 – Interpreting Reality Part 2: Is It Just In My Head? [Auditory Illusion, Fake Memory, Misinformation]

Reflection3:

- How has your outlook changed over the past weeks on the way you think about the world, information, and the way humans learn?
- How has the awareness of the way humans behave change the way you think?
- Do you think less of humans now that you are more aware of human foolishness?
- Do you think that you yourself are more human than you'd like to admit?
- Would you like to change into a better person or do you feel that it's not worth the effort?

Reaction3:

The power of believing that you can improve | Carol Dweck **and Brain Rule #5 Every brain is wired differently (the book chapter)**

- What if I told you that all it takes to improve yourself is "belief", how much do you believe in the power of belief? Explain why or why not.
- What if I told you that all it takes to improve yourself is to wire and re-wire your brain based on how you think, would you be willing to go through the effort?

Lesson 4 – The World Through a New Lens [Mindsets, Mastery & Performance Goal Orientations, Self-Regulation]

Reflection4:

- What thoughts have been circulating your mind since you've watched TEDTalks on mindset change and behavior change?
- What are your thoughts on class discussion (or lack thereof)?

- What are your thoughts on your strategy document?
- Share with me what you've been thinking, and perhaps, what you'd like more from this class?
- Any other thoughts you've been having

Reaction4a

- Watch Change Behavior - Change the World: Joseph Grenny at TEDxBYU
- How do you relate to "I don't know what happened?" responses when the kids were spending all their money?
- What kind of ideas do you get from this video for changing your studying/learning behavior?
- How can you learn the skills that you need to succeed in academics?
- Any other reactions you had from the video

Reaction4b:

- Watch After watching this, your brain will not be the same | Lara Boyd and You can grow new brain cells. Here's how | Sandrine Thuret
- How do you interpret all this information about the brain? Have you heard about these things before?
- How does this motivate you to change the way you treat yourself (or your brain)?

Optional Homework over Thanksgiving Break

- Watch "Stanford Prison Experiment" and/or "Experimenter" on Netflix (If you don't have a Netflix account, perhaps watch it with a friend who has an account.)

Lesson 5 – Engineering the Mind (We did an activity on critiquing "I believe I can achieve anything I want through time and effort")

Reflection5

- Describe any insights you've gained by using the strategy document
- Do you think it's worth putting the time and effort in difficult/challenging things now or do you feel like it's not worth?
- Share what's been on your mind regarding the course or course content

Reaction5a:

- Watch video by Jordan Peterson on "How To Stop Procrastinating"

- Use a dictionary to look up words that you don't know (i.e., conscientiousness, orderliness, industriousness)
- Just in case, The Future Authoring Program is something Peterson created to help people
- The Big Five Personality traits are OCEAN: Openness, Conscientiousness, Extraversion, Agreeableness, Neuroticism (you can look these up, too, but don't get lost in doing personality tests)
- How helpful was this video?
- What do you agree with? What do you disagree with?
- Does this video motivate you to restructure your strategy document? Why or why not?

Reaction5b

- Watch Why you think you're right -- even if you're wrong | Julia Galef and Why we are wrong when we think we are right | Chaehan So
- When was a time you were wrong when you thought you were right?
- When was a time you were right when others thought you were wrong?
- What are your impressions about the content?
- What are your thoughts after having watched these videos? (Have you seen them before?)

Lesson 6 – Interpretation Gone Wrong (We played some games)

Reflection6

- Think about how this class influenced you as a person and an engineer.
- How would you explain the value/importance of this class to your Department Head?
- What are the things you've learned in this class that you would not learn in your regular engineering curriculum?
- Should this class be treated like a liberal arts class or an engineering class? Why?
- If I created a sequel course, what would you like to be implemented in that course?
- Any other final feedback you want to say (especially what you didn't like but you can include specific things you liked).

Reaction6a

- Watch Honest liars — the psychology of self-deception (Cortney Warren)
- What are your impressions about the content?

- As much as you are willing to share, please share any past tough realities you've had to face and how you've grown through it (e.g., friends/family/relationship issues, personal character issues, insecurities)
- As much as you are willing to share, please share any current tough realities that you can admit to and that you're working through?
- How does this TEDTalk discourage you or motivate you?

Reaction6b

- Watch Using our practical wisdom | Barry Schwartz
- What are your impressions about the content?
- Have you ever seen someone exhibit practical wisdom (e.g., movie, tv show, real life)?
- What do you think about bending the rules vs. following the rules?
- How does this TEDTalk discourage you or motivate you?

Strategy Document

Strategy1

- State the course (or research work for one of you) that you're interested in improving in.
- State the goals or objectives you have for that course (e.g., I want to make sure I pass or I want to better understand the concepts, etc.)
- Describe your plan that will help you achieve those goals/objectives (e.g., I want to finish problems sets early, one question per day)
- Describe potential problems you will expect when trying to execute your plan (e.g., distracted by friends)
- Describe potential solutions to these problems (e.g., study in the library away from friends)
- How will you get back on track when you fail? How will you monitor your progress? Do you have any checkpoints?

Strategy2

- Start a new page in your strategy document to document your revisions.
- State the course that you're interested in improving in.

- State your **previous** goals or objectives you have for that course (e.g., I want to make sure I pass or I want to better understand the concepts, etc.) and whether these goals have changed or stayed the same
- Describe your **adjusted** plans that will help you achieve those goals/objectives (e.g., I want to finish problems sets early, one question per day) **and explain your reasoning behind these adjustments**.
- If you encountered unexpected circumstances before, **how will you plan around them this week?**
- **What were your biggest failures in following your strategy document and why?**
- How will you get back on track when you fail? How will you monitor your progress? Do you have any checkpoints? **How will you monitor how you feel?**

Strategy3

- Keep updating your Strategy documents
- Here are the additional strategies I've shared in class:
- <u>Fail log</u> - Keep track of what you did instead of work and why, like "Why I chose to hang out with friend over doing homework"
- <u>Excuse log</u> - What kind of excuses have you tolerated, like "I can just do this tomorrow" or "I don't feel like doing it"
- <u>Unforeseen circumstances log</u> - What kind of "life" problems have happened, like "Car broke down" or "Friend visited from out-of-town"
- Within these logs, write down the consequences of your failures/excuses. Conversely, write down the benefits of not succumbing to these excuses.
- Perhaps, determine 3 tasks you will accomplish for each day, and evaluate your progress at the end of each day

Strategy4

- Continue making adjustments to your strategy document as needed. Explain why you made these changes.

Strategy 5

- Update your strategy documents as you prepare for your final exams. Explain your adjustments.

B.4 Research consent form

Purpose and Procedures:

The purpose of this research is to understand how the "Engineering the Mind" course helps students develop positive learning dispositions. This research is being undertaken as part of Dong San Choi's PhD dissertation that focuses on helping engineering students succeed academically. The investigators include Dr. Geoffrey Herman and Dong San Choi from the University of Illinois at Urbana-Champaign.

Participants will complete all required activities of the course, including pre-post surveys and written assignments. We will collect information on these survey results, written assignments, and additional retention data such as your major and college of enrollment. No personal identifying information will be disseminated. Course instructors will not know your decision to participate until after course grades have been submitted.

Requirements: All participants must be at least 18 years old and taking the course in question.

Participation is voluntary: Participation in this research is voluntary. The decision to participate, decline, or withdraw from participation will have no effect on your grades at, status at, or future relations with the University of Illinois. Participants may change their decision to participate at any time by signing and dating another form, which is available on request.

Benefits and Risks: As a result of participating in the study, participants will help us understand how to better support engineering students both professionally and academically. There will be no risks for participating in this research beyond what can be experienced through daily life.

Compensation: There will be no compensation for participation in this research study.

Confidentiality: Your survey results are linked to your identification codes, but course instructors do not know whose name is linked to those codes so as to protect your anonymity. Your names on written assignments will be replaced with a different identification code by Dong San Choi so that the results of this research will disclose no personally identifying information. Results from this research will be published in relevant engineering education conferences and journals. Faculty, staff, students, and others with permission or authority to see your study information will maintain its confidentiality to the extent permitted and required by laws and university policies. The names or personal identifiers of participants will not be published or presented.

Whom to contact with questions: Questions about this research should be directed to Dr. Geoffrey Herman (glherman@illinois.edu). If you feel you have not been treated according to the descriptions in this form, or if you have any questions about your rights as a research subject, including questions, concerns, complaints or to offer input, you may call the Office for the Protection of Research Subjects (OPRS) at 217-333-2670 or email OPRS at irb@illinois.edu. By selecting one of the options below, you certify that you have read and understand what has been stated in this form.

______ I agree to have my survey responses, course assignments, and retention information, such as major and college of enrollment, be collected and used for the purposes of this research AND I am at least eighteen years of age.

______ I do NOT agree to have my survey responses, course assignments, nor retention information be used for this research OR I am not at least eighteen years of age.

______________________________ ____________________________ __________

Signature Print Date